Scientific Advice on Matters Related to the Management of Seal Populations: 2020

Contents

Executive Summary

Under the Conservation of Seals Act 1970 and the Marine (Scotland) Act 2010, the Natural Environment Research Council (NERC) has a duty to provide scientific advice to government on matters related to the management of UK seal populations. NERC has appointed a Special Committee on Seals (SCOS) to formulate this advice. Questions on a wide range of management and conservation issues are received from the UK government and devolved administrations. In 2020, 31 questions were received from Marine Scotland, Defra and Natural Resources Wales. SCOS's answers to these questions are provided in detail in the main Advice below and summarised here.

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

The most recent synoptic surveys of the principal grey seal breeding sites in the Inner and Outer Hebrides and Orkney were carried out in 2016. A partial aerial survey was completed in 2018 allowing estimation of pup production for the colonies in the Firth of Forth which were combined with ground counts for the colonies on the east coast of England to provide a 2018 pup production for the North Sea. With a correction for less frequently monitored sites in Shetland, Wales, SW England, Northern Ireland and scattered locations throughout Scotland the best estimate for pup production in the UK in 2018 was 68,050 (approximate 95% CI 60,500-75,100) pups born throughout the UK (Table S1). A complete census covering Orkney, Inner and Outer Hebrides and the North Sea colonies was completed in 2019 and results will be presented in 2021.

The pup production estimates are converted to estimates of total population size (1+ aged population at the start of the breeding season) using a mathematical model. The population model provided an estimate of **149,700 individuals (approximate 95% CI 120,000-174,900).**

Summary *Table s1.* ***Grey seal pup production by country (based on 2016-2018 pup production estimates), and total population estimates at the start of the 2019 breeding season***

Location	Pup production in 2016	2019 Population estimate
England	**10,350**	**28,400**
Wales	**2,250**	**5,000**
Scotland	**55,200**	**115,750**
Northern Ireland	**250**	**550**
Total UK	**68,050**	**149,700**

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

Current status of British harbour seals (*Phoca vitulina*)
Harbour seals are counted while they are on land during their August moult, giving a minimum estimate of population size. Not all areas are counted every year, but the aim is to cover the UK coast every 5 years. The estimated total population for the UK and Northern Ireland in 2019 was 44,100 (approximate 95% CI: 36,100-58,800), based on the most recent composite count of 31,744,

(based on surveys between 2016 and 2019) and a correction for the estimated proportion hauled out during the surveys (0.72 (95% CI: 0.54-0.88)). Overall, the UK population has increased since the late 2000s and is close to the 1990s level. However, there are significant differences in the population dynamics between seal management units (SMUs).

Until recently, harbour seal populations along the English East coast had generally increased year on year, with those increases punctuated by major declines associated with two major Phocine Distemper Virus (PDV) epizootics in 1988 and 2002. However, the 2019 count in the large Southeast England SMU was approximately 27% lower than the mean of the previous 5 years and may indicate the start of a decline.

Populations along the East coast of Scotland and in the Northern Isles have generally declined since the early 2000s. The recorded declines have differed in intensity but in all areas the current population size is at least 40% below the pre-2002 level. Populations in North Coast & Orkney SMU and in the Tay and Eden SAC are continuing to decline. Although continued declines are not evident in Shetland or the Moray Firth, there is no indication of recovery.

Populations in western Scotland are either stable or increasing. Counts in the central section of the large West Scotland SMU have been increasing since the 1990s and in all other areas they have remained stable. In Northern Ireland, the population appears to have declined slowly after 2002 but has been apparently stable since 2011.

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

Location	Most recent count (2016-2019)	Total Population estimates with 95% CIs	
England	**3,900**	**5,400**	**(95% CI 4,400-7,200)**
Wales	**<10[1]**		**<15**
Scotland	**26,800[2]**	**37,200**	**(95% CI 30.400-49,600)**
Northern Ireland	**1,000**	**1,400**	**(95% CI 1,100-1,900)**
Total UK	**31,700**	**44,000**	**(95% CI 36,000-58,700)**

Knowledge of UK harbour seal demographic parameters (i.e. vital rates) is limited and therefore inferences about the population dynamics rely largely on count data from the moulting surveys.

Information on the causes of the declines in harbour seals in some Scottish SMUs is required for SCOS to advise on appropriate conservation actions. A wide range of potential causes have been discussed at previous SCOS meetings. Details of the current state of knowledge for each of the potential drivers of decline were discussed and a summary is presented in table 7. Research efforts are currently focussed on competition and direct predation by grey seals, predation by killer whales, and exposure to toxins from harmful algae.

Seal management

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

The Potential Biological Removals (PBR) is a relatively simple metric developed to provide advice on the levels of removals from a marine mammal population that would still allow the population to approach a defined target. PBR estimates for both harbour and grey seals for each seal management unit in Scotland are presented (Tables 8 & 9), based on suggested values for the recovery factor and the latest confirmed counts in each management area. SCOS recommend that recovery factors be held constant this year, for both species in all SMUs. The latest harbour seal survey counts for the North coast and Orkney, and for the Moray Firth SMUs were similar to previous counts so there has been no change in the harbour seal PBR estimates for those management units. The grey seal counts for the North coast and Orkney, and the Shetland SMUs were approximately 12% and 35% respectively lower than previous estimates and the Moray Firth count was 115% higher than the previous count. These changes result in pro-rata changes in PBRs for grey seals in those SMUs.

The SCOS discussed implications of the changes to the Conservation of Seals Act (1970), the Marine (Scotland) Act (2010) and the Wildlife (Northern Ireland) Order 1985. The facility to allow shooting of seals to protect fisheries and aquaculture operations has been removed from the legislation in all three cases. In previous years, SCOS has identified a need for reporting of the numbers of seals shot to defend fisheries, and therefore not requiring a licence in England and Wales. As the amendments to seal legislation have removed the permission to shoot seals for protection of fisheries throughout the UK there should now be no requirement for such reports.

SCOS highlighted the inconsistency in regulations in different parts of the UK regarding seal protection and specifically the protection of seals at haulout sites from deliberate harassment. At present there is no monitoring in place to determine the effectiveness of such designations of Scottish haulout sites in reducing disturbance. Monitoring would be desirable to enable such an assessment to be made in the future.

Seal Bycatch

The most recent estimated bycatch of seals in UK fisheries was 474 animals (95% CI 354-911) in 2018. This is almost exclusively in gill net fisheries and 85% of the bycatch occurs in the south-west, in ICES area VII.

Estimated bycatch levels in the Western Channel and Celtic Sea exceed the PBR for the combined grey seal populations of SW England, Wales and Ireland. Despite the bycatch, grey seal populations in Wales and Ireland are increasing, suggesting that bycaught seals include animals that may have originated from the large, adjacent breeding populations in western Scotland.

SCOS discussed the current SMU structure and its suitability for managing anthropogenic issues at differing spatial scales. Measures for combining SMU populations to address wide ranging issues such as bycatch were discussed. However, determining the appropriate spatial scale for managing populations relies on information on the extent of movement between SMUs and, in the absence of much of that information, decisions about scale of management are policy decisions.

Interactions with Fisheries

SCOS discussed a range of topics related to seal interactions with fisheries and aquaculture. Answers are presented to queries on a range of topics including non-lethal methods for protecting fisheries and marine aquaculture operations from depredation by seals, effectiveness of acoustic deterrent devices, welfare issues associated with disturbance of seals at haulout sites and the alternative methods of lethal removal of seals.

Interactions with Marine Renewable Energy developments

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

Results of harbour seal tracking studies in the Pentland Firth show that they avoided a tidal turbine array when it was operating, with reduced seal densities out to 2km range. A playback study with tagged free-ranging harbour seals detected avoidance responses to a simulated tidal turbine signal at ranges up to 500m. Important data gaps still exist, e.g. the responses of seals to large scale arrays cannot be tested because there are no large arrays; there is little information on fine scale behaviour in the vicinity of turbines.

Climate change and marine pollution.
SCOS discussed the available information on the likely impacts of climate change on UK seal populations and on the available information on effects of macro- and micro-plastic pollution on UK seals. Summaries of these discussions are presented.

Scientific Advice

Background

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

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

This report provides scientific advice on matters related to the management of seal populations for the year 2020. It begins with some general information on British seals, gives information on their current status, and addresses specific questions raised by Marine Scotland (MS) and the Department of the Environment, Food and Rural Affairs (Defra) and Natural Resources Wales (NRW).
Briefing papers which provide additional scientific background for the advice are appended to the main report.

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

General information on British seals

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

Grey seals

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

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

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

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

Approximately 36% of the world's grey seals breed in the UK and 81% of these breed at colonies in Scotland with the main concentrations in the Outer Hebrides and in Orkney. There are also breeding colonies in Shetland, on the north and east coasts of mainland Britain and in SW England and Wales. In the UK, grey seals typically breed on remote, uninhabited islands or coasts and in small numbers in caves. Preferred breeding locations allow females with young pups to move inland away from busy beaches and storm surges. Seals breeding on exposed, cliff-backed beaches and in caves may have limited opportunity to avoid storm surges and may experience higher levels of pup mortality as a result. Breeding colonies vary considerably in size; at the smallest only a handful of pups are born, while at the biggest, over 5,000 pups are born annually. In the past, grey seals have been highly sensitive to disturbance by humans, hence their preference for remote breeding sites. However, at one UK mainland colony at Donna Nook in Lincolnshire, seals have become habituated to human disturbance and over 70,000 people visit this colony during the breeding season with no apparent impact on the breeding seals.

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

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

Harbour seals

Adult harbour seals typically weigh 80-100 kg. Males are slightly larger than females. Like grey seals, harbour seals are long-lived with individuals living up to 20-30 years. They normally feed within 40-50 km around their haul out sites. They take a wide variety of prey including sandeels, gadoids, herring and sprat, flatfish, octopus and squid. Diet varies seasonally and from region to region. Because of their smaller size, harbour seals eat less food than grey seals; 3-5 kg per adult seal per day depending on the prey species.

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

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

Approximately 32% of European harbour seals are found in the UK; this proportion has declined from approximately 40% in 2002 due to the more rapid recovery and higher sustained rates of increase in the Wadden Sea population. Harbour seals are widespread around the west coast of Scotland and throughout the Hebrides and Northern Isles. On the east coast, their distribution is more restricted with concentrations in the major estuaries of the Thames, The Wash and the Moray Firth. Scotland holds approximately 85% of the UK harbour seal population, with 12% in England and 3% in Northern Ireland.

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

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

Historical status

We have little information on the historical status of seals in UK waters. Remains have been found in some of the earliest human settlements in Scotland and they 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. Large scale culls of grey seals in the North Sea, Orkney and Hebrides were carried out in the 1960s and 1970s as population control measures. Grey seal pup production monitoring started in the late 1950s and early 1960s and numbers have increased consistently since. However, in recent years, there has been a significant reduction in the rate of increase.

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

Legislation protecting seals

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

In Scotland, the Conservation of Seals Act was superseded by the Marine (Scotland) Act 2010. As a result, the conservation orders in Scotland have been superseded by the designation of seal conservation areas under the provisions of the Marine (Scotland) Act 2010. Conservation areas have been established for the Northern Isles, the Outer Hebrides and the East coast of Scotland. In general, seals in Scotland are afforded protection under Section 6 of the Act which prohibits the killing or taking of seals except under licence. In the original version of the Act, licences could be granted for ten specific reasons, including to conserve natural habitats, for scientific, research or educational purposes, to protect the health and welfare of farmed fish and to prevent serious damage to fisheries or fish farms' aquaculture activities. Recent legislative changes in Scotland, via the Animals and Wildlife (Penalties, Protections and Powers) (Scotland) Act 2020, have amended the Marine (Scotland) Act 2010 to remove the provision to grant licences authorising the killing or taking of seals to protect the health and welfare of farmed fish, and 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, amends the Conservation of Seals Act 1970 and the Wildlife (Northern Ireland) Order 1985, prohibiting the intentional or reckless killing, injuring or taking of seals and removing the provision to grant licences for the purposes of protection, promotion or development of commercial fisheries or aquaculture activities. These changes were enacted to ensure compliance with the US Marine Mammal Protection Act Import Provision Rule.

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

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

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

SCOS 2020: Questions from Marine Scotland, Department for Environment, Food and Rural Affairs and Natural Resources Wales.

Questions for SCOS 2020 were received from the three mainland administrations (Marine Scotland (MS); Department for Environment, Food and Rural Affairs (Defra); Natural Resources Wales (NRW)) and are listed in Annex II. Some of these questions were essentially the same, requiring regionally specific responses in addition to a UK wide perspective. These very similar questions were therefore amalgamated, with the relevant regional differences in response being given in the tables and text. The question numbers by administration are shown in the boxes for cross reference. The remaining questions were regionally unique, requiring responses that focussed on the issue for a given area. The questions are grouped under topic headings, in the order and as they were given from the administrations.

Seal Populations

1. **What are the latest estimates of the number of seals in UK waters**?	MS Q1 Defra Q1a NRW Q3a

Current status of British grey seals

The total UK grey seal population of at the start of the 2019 breeding season (before pups are born) is estimated at 149,700 individuals (approximate 95% CI 120,000-174,900). The estimate is based on the most recent pup production estimates in 2016 for aerial surveyed colonies in Orkney and the Inner and Outer Hebrides, Scotland and 2018 for combined aerial and ground surveyed colonies in the North Sea, Details are provided in SCOS-BP 20/01 and below and estimates by country are presented in Tables 1 and by region within the British Isles in Table 2.

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

The most recent synoptic census of the principal grey seal breeding sites in Orkney, the Inner and Outer Hebrides were carried out in 2016 and sites in the Firth of Forth were surveyed in 2018. Results from these aerial surveys together with the 2018 estimates from ground counted sites in eastern England and a correction for less frequently monitored sites produce an estimate of 68,050 (approximate 95% CI 60,500-75,100) pups born throughout the UK (Tables 1 & 2) in 2018. A complete survey programme covering Orkney, Inner and Outer Hebrides and the North Sea colonies was completed in 2019 and results will be presented in 2021.

The regional pup production estimates for 1984 to 2016 for the Inner Hebrides, Outer Hebrides and Orkney and for 1984 to 2018 for the North Sea colonies were converted to estimates of total population size (1+ aged population, referred to as 'adult population') at the start of the 2019 breeding season, using a mathematical model of British grey seal population dynamics. The population estimate is then corrected to account for pup production at less frequently monitored

colonies. The stages in the process, the fitting of the pup production model and the observed trends are described below and presented in SCOS-BPs 20/01, 19/01, 18/02 and 20/02, Russell *et al. (*2019) and Thomas *et al. (*2019).

Pup Production

Major colonies in Scotland are now surveyed biennially (see SCOS-BP 14/01). Aerial surveys to estimate grey seal pup production were carried out in Scotland in 2016, using a digital camera system for the third time. Counts then go into a model to estimate pup production on the biennially monitored colonies around Scotland.

Table 1 ***Grey seal pup production by country (based on 2016-2018 pup production estimates), and total population estimates at the start of the 2019 breeding season.***

Location	Pup production in 2016*	2019 Population estimate**
England	**10,350***	**28,400**
Wales	**2,250***	**5,000**
Scotland	**55,200**	**115,750**
Northern Ireland	**250***	**550**
Total UK	**68,050**	**149,700**

*Includes estimated production for less frequently monitored colonies, see Table 2 and SCOS-BP 18/01 and 20/04 for details. Populations associated with these estimates were based on the average ratio of pups to total population for the regularly monitored sites.
** Populations derived from the 2016 pup production estimates except for North Sea colonies where a 2018 pup production estimate is included. Confidence intervals are not provided as the national populations have been derived from regional population estimates scaled by proportions of that region's pup production in each country

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

Pup productions at the major colonies on the East coast of England are estimated annually from ground counts carried out by conservation bodies responsible for those sites (Lincolnshire Wildlife Trust at Donna Nook; National Trust at the Farne Islands and Blakeney Point; Friends of Horsey Seals and Royal Society for Protection of Birds at Horsey). Differences between ground counts and a preliminary air survey count in 2014, as well as differences between the counting methodologies at the main sites in England (the Farne Islands, Donna Nook, Blakeney and Horsey) make it difficult to incorporate these data into the population estimation models. The cancellation of the late survey flights over the main Scottish breeding sites provided an opportunity to carry out a full aerial survey programme for the English breeding sites, to provide a direct comparison with the ground count data for 2018. Using the previous ground count data to estimate the optimum survey dates, we extended the Firth of Forth site surveys to cover the four English east coast colonies. Five surveys were carried out of the Isle of May, Fast Castle and Farne Islands colonies and four surveys were carried out of the Donna Nook, Blakeney and Horsey colonies. Analysis is continuing and results from these surveys will be presented at SCOS 2021. However, survey counts from the Isle of May, Fast Castle and the Firth of Forth are available and have been combined with pup production estimates from the ground counted colonies on the English east coast to generate a pup production estimate for the North Sea colonies in 2018.

The ground count data, combined with estimates from less frequently aerially surveyed colonies, indicated that the current best estimate of total number of pups born in 2018 across all UK colonies was approximately 68,050 (approximate 95% CI 60,500-75,100).

Regional pup production estimates in 2016 at biennially surveyed colonies were: 4,500 (approximate[1] 95% CI 3,900-5200) in the Inner Hebrides, 15,700 (95% CI 13,700-18,200) in the Outer Hebrides, 23,800 (95% CI 20,700-27,550) in Orkney and 14,600 (95% CI 12,700-16,900) at the North Sea colonies (including Isle of May, Fast Castle, Farne Islands, Donna Nook, Blakeney Point and Horsey/Winterton) (SCOS-BP 18/01). The 2018 estimate for the North Sea colonies was 16,800 (approximate 95% CI 14,600-19,500), approximately 14% higher than the 2016 estimate.

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

Trends in pup production

There has been a continual increase in the total UK pup production since regular surveys began in the 1960s (Figure 1) (see SCOS-BP 18/01 & Russell *et al.* (2019) for details). Interpretation of the trends in pup production are complicated by a change in survey methodology after 2010. Improved camera technology and reduced survey height may have changed both the efficiency of counting and the stage classification of pup images. Technical problems, aircraft availability and loss of film processing capability precluded direct cross calibration of the old and new methods. The pup production estimates at the regularly monitored colonies showed a step change increase coincident with the change in methodology. This change was shown to be mainly due to the change in methodology, but the magnitude of the effect is not precisely known. Investigation of the potential effects of these methodological changes is ongoing.

A detailed description of the trends in pup production up to 2010, at regional and colony levels is presented in Russell *et al.* (2019). Between 2000 and 2010, i.e. prior to the change in technique, the pup production estimates had remained stationary in the Inner Hebrides and declined at an average of 1% p.a. in the Outer Hebrides. In both the Inner and Outer Hebrides, the estimated pup production increased between 2014 and 2016 at 6% p.a. and 5% p.a. respectively. In Orkney, the estimated 2016 pup production was the same as the 2014 estimate and similar to the 2012 estimate. Pup production in Orkney increased by <1% p.a. between 2012 and 2016. As in the Hebrides, the rate of increase in Orkney has been low since 2000, with pup production increasing at around 1.4% p.a. between 2000 and 2010.

In all three regions where the pup production is estimated entirely from aerial survey counts there was an apparent step change coincident with the transition to a new digital camera system. For logistical and technical reasons, it has not been possible to directly cross-calibrate the two methods.

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

However, as the new time series extends it becomes easier to estimate the magnitude and nature of these changes. A preliminary analysis of the effects suggests that the effect will be colony and substrate specific and has implications for the selected values of some of the parameters in the pup production model. The current pup production model is fully described in Russell *et al.* (2019). A series of sensitivity analyses are under way.

Pup production at colonies in the North Sea continued to increase rapidly up to 2016 (Table 2). These show an annual increase of 7.5% p.a. between 2014 and 2018, slightly less than the 11.5% p.a. between 2010 and 2016. The majority of the increase in the North Sea has been due to the continued rapid expansion of newer colonies on the mainland coasts in Berwickshire, Lincolnshire, Norfolk and Suffolk. Interestingly, these colonies are all at easily accessible sites on the mainland, where grey seals have probably not bred in significant numbers since before the last ice age.

The estimated pup production at the Farne Islands increased dramatically, by >18% p.a. between 2014 and 2016, while the more southerly mainland colonies increased by an average of 8.5% p.a. which is substantially lower than the average 22% p.a. increase between 2010 and 2014. Additional estimates are available for the ground counted colonies on the English east coast, for the Farne Islands up to 2018, and for Donna Nook, Blakeney and Horsey up to 2019. Rates of increase since 2014 vary: 4% p.a. at Donna Nook, 7%p.a. at Blakeney, 12%p.a. at the Farne Islands and 24% p.a. at Horsey.

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

There are no or very few grey seals in south Wales (Caldey Island – Bristol Channel). Intensive monitoring of pup production is primarily focussed at three sites: Bardsey Island, parts of Ramsey Island, and Skomer Marine Conservation Area. Other areas have been monitored more sporadically, and within a season, less intensively. North Wales wide surveys have been conducted in 2001, 2002 and 2017. The latest pup production estimate for 2017 was 216. West Wales wide surveys were conducted in 1992, 1993, and 1994.

It is not possible to estimate trends in pup production on a SMU scale. Pup production at Ramsey Island indictor sites has been variable but shown little trend. There is an upward trend in pup production at Skomer MCZ, though the trend is variable.

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

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

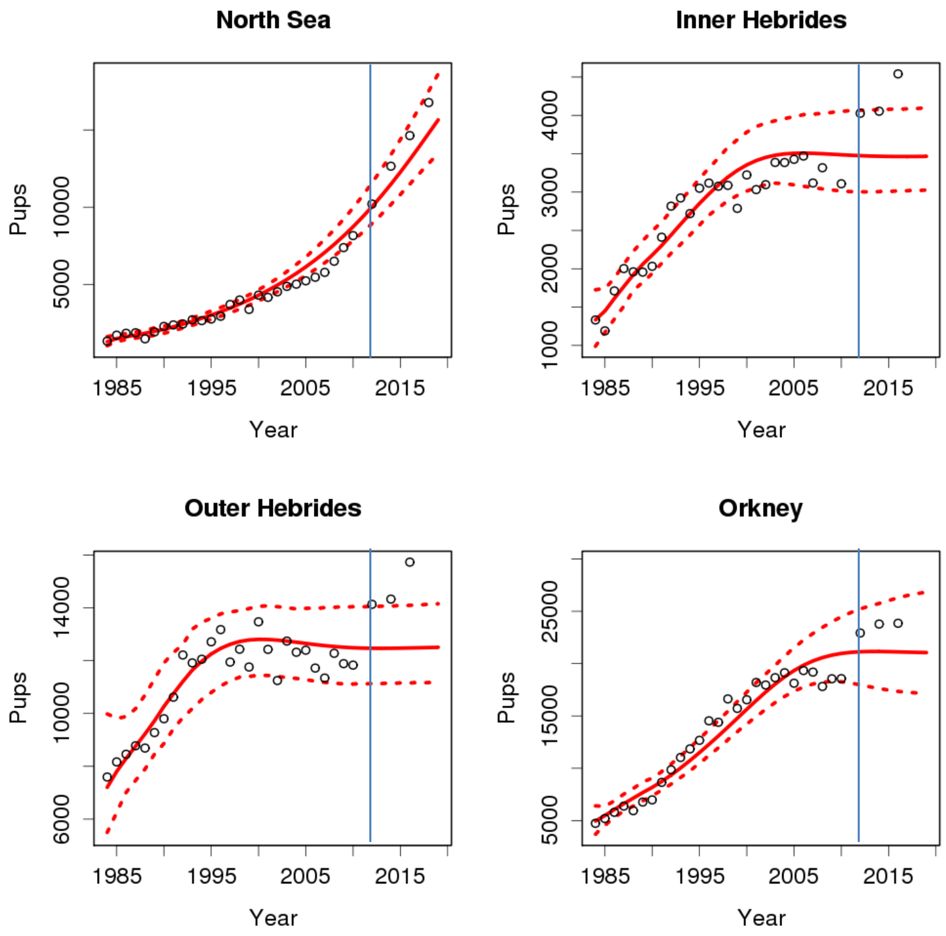

Figure 1. *Posterior mean estimates of pup production (solid lines) and 95% Confidence Intervals (dashed lines) from the model of grey seal population dynamics, fit to pup production estimates for regularly monitored colonies (SCOS-BP 18/01 and Table 2 below), from 1984-2016 (circles) for colonies in Orkney and the Inner and Outer Hebrides, and for 1984-2018 for the colonies in the North Sea, and two independent total population estimates from 2008 and 2014 (see text for details). The vertical blue line at 2012 indicates the change to a new camera system.*

Table 2 ***Grey seal pup production estimates used to generate estimates of the grey seal population at the start of the 2019 breeding season. Counts from 2016 aerial surveys for the regularly monitored colonies in Orkney and the Inner and Outer Hebrides, 2018 aerial surveys for Firth of Forth colonies and 2018 ground counts for English North Sea colonies are combined with most recent data from less regularly monitored colonies*** *(see main text and SCOS-BP 18/01 for details).* ***These estimates are compared with production estimates from 2014***

Location	Latest pup production in **2016 & 2018**		Pup production in 2014		Average annual change since 2014
Inner Hebrides	4,541	1	4,054		+5.8%
Outer Hebrides	15,732	1	14,331		+4.8%
Orkney	23,849	1	23,776		+0.2%
Firth of Forth	6,894	2	5,860		+4.2%
Main biennially monitored Scottish island groups	**51,016**		**48,021**		**+2.6%**
Other Scottish colonies [1] (incl. Shetland & mainland)	4,200	3	3,875	1	+4.0%
Total Scotland	**55,216**		**51,896**		**+2.7%**
Donna Nook +East Anglia	7,147	2	5,027		+9.2%
Farne Islands	2,737	2	1,740		+14.4%
Annually monitored colonies in England	**9,884**		**6,795**		**+10.9%**
SW England (last surveyed 2018)	450	4	250	3	
Total England	**10,334**		**7,045**	3	
Total Wales	**2,250**	**4**	**1,650**	3	**+8.6%**
Total Northern Ireland	**250**	**5**	**100**	3	
Total UK	**68,050**		**60,691**		**+3.7%**

1 Estimates derived from 2016 aerial surveys

2 Estimates derived from 2018 aerial surveys of Firth of Forth sites and 2018 ground counts of English east coast colonies

3 Estimates derived from ground counts in Shetland and aerial surveys of sites on the mainland coast and smaller Hebridean Islands. Data collected in different years and includes estimated production for colonies that are rarely monitored

4 Combination of survey counts of most colonies in 2018 and an estimate for other colonies based on a multiplier derived from 2004 survey results. These numbers differ from those in *SCOS-BP 18/01 see SCOS-BP 20/04*

5 Includes estimated production for colonies that are rarely monitored

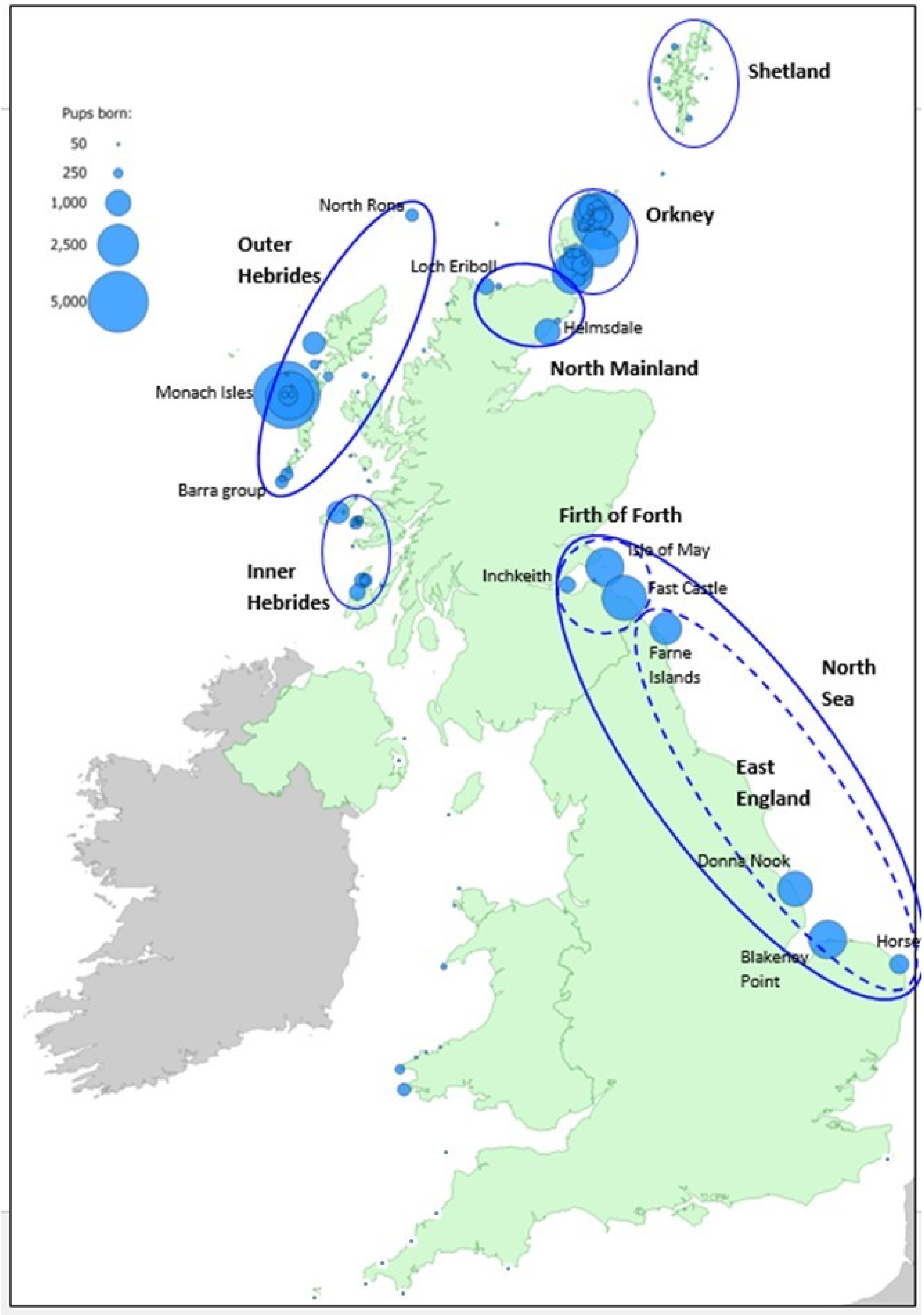

Figure 2. *Distribution and size of the main grey seal breeding colonies. Blue ovals indicate groups of regularly monitored colonies within each region.*

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

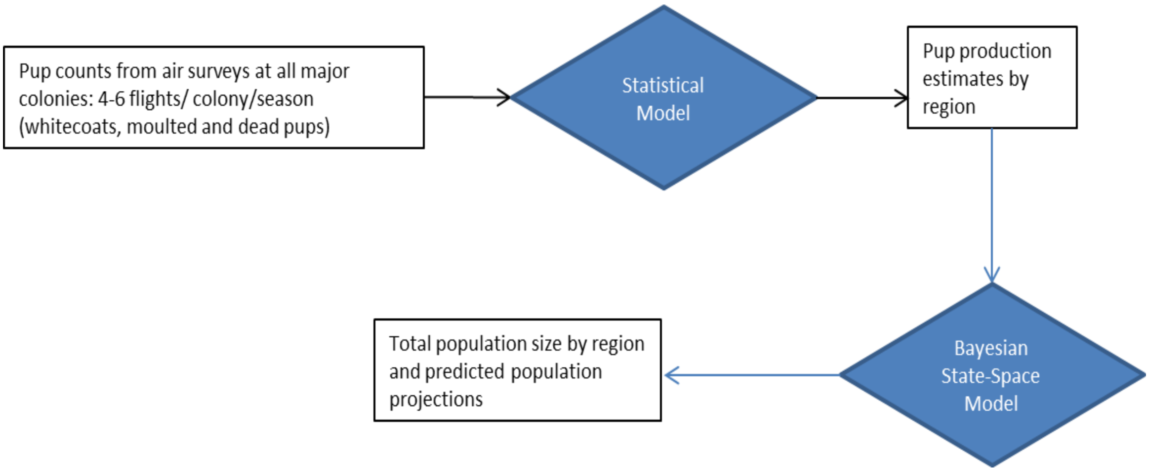

Figure 3. *Schematic diagram of steps involved in estimating total grey seal population size from pup counts (see also SCOS BP-09/02, SCOS BP-10/02).*

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

Data from surveys with consistent methodology indicate that from at least 1984 until the late 1990s all the regional populations grew exponentially, implying that the demographic parameters were, on average, constant over the period of data collection. Thus, estimates of the demographic parameters were available from a simple population model fitted to the entire pup production time series. Some combination of reductions in the reproductive rate or the survival rates of pups, juveniles and adults (SCOS-BPs 09/02, 10/02 and 11/02) has resulted in reduced population growth rates in the Northern and Western Isles.

To estimate the population size, we fitted a Bayesian state-space model of British grey seal population dynamics. Initially, alternative models with density dependence acting through either fecundity or pup survival were tested, but results indicated that the time series of pup production estimates did not contain sufficient information to quantify the relative contributions of these factors (SCOS-BPs 06/07, 09/02). In 2010 and 2011, we incorporated additional information in the form of an independent estimate of population size. This was based on counts of the numbers of grey seals hauled out during the summer and information on their haulout behaviour, which provides an estimate of the proportion of the population available to be counted during the aerial surveys (SCOS-BP 10/04 and 11/06). Between 2007 and 2009, 26,699 grey seals were counted during harbour seal moult surveys across the UK (excluding southwest UK). Using telemetry data, it was estimated that 31% (95% CIs: 15 - 50%) of the population was hauled out during the survey window and thus available to count (Lonergan *et al., 20*11). Assuming 4% of the population were in southwest UK, this led to a UK independent population estimate in 2008 of 91,800 (95% CI: 78,400 - 109,900).

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

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

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

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

In 2012, SCOS discussed the priors on the model input parameters in some detail, following re-examination of the data being used and the differences made to the population estimates by changing a number of them to less informative priors (SCOS-BP 12/01 and SCOS-BP 12/02). In 2014 SCOS decided to use the results from a model run using these revised priors (SCOS-BP 12/02) and incorporating a prior based on a distribution for the ratio of males to females in the population (see SCOS-BP 14/02 for details) and the independent estimate of total population size from the summer surveys. Work on updating these priors is continuing and an annual update is presented in SCOS-BP 20/02. A re-analysis of all the combined data available from pup tagging studies (hat tags, phone tags and GPS/GSM tags) suggested that there were no significant sex-specific differences in first year pup survival. SCOS-BP 20/02 presents details of prior distributions used in the model and the justification for the selected values.

In 2014, SCOS adopted a set of revised priors, including a different prior on adult sex ratio, to generate the grey seal population estimates. The model produced unreasonably high adult survival values of more than 0.99, so it was re-run with a prior on survival constrained to what was considered to be a more reasonable range of 0.8 to 0.97. Posterior mean adult survival with this revised prior was 0.95 (SD 0.03). The upper bound of the adult survival prior was increased slightly to 0.98 in line with revised survival estimates.

This year, an identical model equivalent to the main analysis in 2018 and 2019 was fitted to the pup production estimates from 1984 to 2016 for the Inner Hebrides and Outer Hebrides and Orkney (Table 2) and for 2018 for the North Sea colonies, and independent estimates of population size from 2008 and 2014.

The model allowed for density dependence in pup survival, using a flexible form for the density dependence function, and assumed no movement of recruiting females between regions. The same model and prior distributions for demographic rates were used, including a prior on sex ratio and a constraint on adult survival to the range 0.80-0.98. The revised prior on North Sea carrying capacity of 20,000 was used as the population produced over 14,000 pups but continues to increase rapidly, indicating that it was not close to carrying capacity.

Grey seal population estimate

From the standard model run, the estimated adult class population size (here taken to mean the total 1+ age population) in the regularly monitored colonies at the start of the 2019 breeding season was 133,900 (95% CI 115,300-156,500). This estimate is produced by a model incorporating density dependent pup survival, using the revised priors and including the independent estimates for 2008 and 2014 (details of this analysis and posterior estimates of the demographic parameters are given in SCOS-BP 20/01 and SCOS-BP 20/02).

A comprehensive survey of data available from the less frequently monitored colonies was presented in SCOS-BP 18/01 and revised estimates for Southwest England, Wales, Northwest England, and Northern Ireland are presented in SCOS-BP 20/04. Total pup production at these sites was estimated to be approximately 7,150. The total population associated with these sites was then estimated using the average ratio of pup production to population size estimate for all annually monitored sites in 2016. Approximate confidence intervals were estimated by assuming that they were proportionally similar to the population dynamics model confidence intervals for the standard model run. This produced a population estimate for these sites of 15,700 (approximate 95% CI 13,500 to 18,400). Combining this with the annually monitored sites gives an estimated 2019 UK grey seal population of 149,700 (approximate 95% CI 129,000-174,900).

Potential problems associated with transition to the new digital methods have also highlighted potential sensitivity of the pup production estimates to some of the parameter estimates used. These aspects of the pup production model are being investigated. A detailed description of the model and the pup production trajectories is presented in Russell *et al.* (2019). A detailed analysis of the effects of changing parameters is underway as part of a process to develop a new Bayesian pup production model. As a preliminary to that development, two additional runs of the population dynamics model were carried out in 2018 with different versions of one of these parameters, the estimated misclassification of moulted pups as white coated pups (PCORRECTMOULT) and the effect of including the recent digital pup count data. These were reported in SCOS-BP 18/03

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

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

The fit of the model to the pup production estimates has been poor in some regions in recent years. Whilst the model accurately captures some aspects of the observed trends in pup production in some regions, the estimated adult survival rate from the model was very high and the maximum pup survival rate was very low. This suggests some other parameters, such as inter-annual variation in fecundity or survival senescence could be causing a mismatch between the estimates from the model and the pup production data.

In 2018, the mode of the posterior distribution on adult survival from the population dynamics model was close to the upper bound 0.97 of the prior. In addition, mark-recpature-based estimates of adult female survival at Sable Island in Canada were higher than this upper bound (0.976, SE 0.001) (denHeyer & Bowen, 2017). Hence, the prior for adult female survival was increased to 0.98 for this year's model runs.

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

In addition, the model assumes a fixed CV for the pup production estimates and obtains this value from an initial model run. Ideally, region-level estimates of pup production variance would be produced as part of fitting the pup production model to the aerial pup count data. These developments are ongoing. One factor that will require consideration is how to incorporate uncertainty in the ground counts made at some North Sea colonies. A set of four aerial surveys were carried out for each of these ground-counted North Sea colonies. Counts and comparison with the 2018 ground counts are ongoing and will be presented to SCOS 2021. A revised pup production model is being developed with the aim of re-estimating pup production for the entire count data set.

Population trends

Model selection criteria suggest that density dependence is acting mainly on pup survival (see SCOS-BP 09/02). The independent population estimate from 2008 was consistent with this conclusion. Although the 2014 independent estimate and revised 2008 estimate have allowed the model to fit a higher trajectory, they are still consistent with the density dependent pup survival model. This also implies that the overall population should closely track the pup production estimates when experiencing density dependent control, as well as during exponential growth. The model run with the full data set and variable PCORRECTMOULT estimated that total population sizes for the biennially monitored colonies have increased by approximately 1.4% p.a. (SCOS-BP 20/01) between 2012 and 2019. All of this is due to a continuing increase in the North Sea population, although even here the rate of increase is reducing, averaging 4.5% p.a. over the past five years compared to 6.5% p.a. over the previous five years ; the Inner and Outer Hebridean and Orkney populations are effectively stationary having not changed since 2012 (SCOS-BP 20/01).

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

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

UK grey seal population in a world context

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

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

Region	Pup Production	Year	Possible population trend
UK	**68,050**	2016-2018	Increasing
Ireland	2,100	2012[1]	Increasing
Wadden Sea	1,700	2020[2]	Increasing
France	70	2019[4]	increasing
Norway	650	2014-18[3]	Possible decline
Russia	800	1994	Unknown
Iceland	1,450	2017[8]	Declining
Baltic	8,000	2019[4,5]	Increasing
Europe excluding UK	**14,800**		unknown
Canada - Scotian shelf	88,200	2016[6]	Increasing
Canada - Gulf St Lawrence	10,500	2016[6]	Increasing
USA	6,250	2019[7]	Increasing
WORLD TOTAL	**187,800**		Increasing

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

[2] Brasseur S.,Carius F., Diederichs B., Galatius A., Jeß A., Körber P., Schop J., Siebert U., Teilmann J., Bie ThøstesenC.& Klöpper S. (2020) EG-Sealsgrey seal surveys in the Wadden Sea and Helgoland in 2019-2020. Common Wadden Sea Secretariat, Wilhelmshaven, Germany.

[3]Nilssen, K.T. and Bjørge, A. 2017a. Havert og steinkobbe [Grey and harbour seals]. Pages 68–69 in I.E. Bakketeig, M. Hauge & C. Kvamme (eds). Havforskningsrapporten 2017. Fisken og havet, særnr, 1-2017. 98 pp.

[3]Nilssen, K.T. and Bjørge, A. 2017b. Status for kystsel. Anbefaling av jaktkvoter for 2018 [Status for coastal seals. Recommendation for harvest quotas for 2018]. Document to the Norwegian Marine Mammal Scientific Advisory Board, October 2017. 9 pp.

[4] ICES. 2020. Working Group on Marine Mammal Ecology (WGMME). ICES Scientific Reports. 2:39. 85 pp. http://doi.org/10.17895/ices.pub.5975. .

[5]Baltic pup production estimate based on mark recapture estimate of total population size (38,000) and an assumed multiplier of 4.7 HELCOM fact sheets (www.HELCOM.fi) & http://www.rktl.fi/english/news/baltic_grey_seal.html

[6] M.O. Hammill, den Heyer, C.E., Bowen, W.D., and Lang, S.L.C. 2017. Grey Seal Population Trends in Canadian Waters, 1960-2016 and harvest advice. DFO Can. Sci. Advis. Sec. Res. Doc. 2017.

[7] Wood *et al.* 2020 Journal of Mammalogy, 101(1):121–128, 2020DOI:10.1093/jmammal/gyz184

[8] Granquist, S.M. and Hauksson, E. 2019. Aerial census of the Icelandic grey seal (*Halichoerus grypus*) population in 2017: Pup production, population estimate, trends and current status. Marine and Freshwater Research Institution, HV 2019-02. Reykjavík 2019. 19 pp. https://www.hafogvatn.is/static/research/files/1549015805-hv2019-02pdf.

Table 3 shows the relative sizes and status of grey seal populations throughout their range. Pup production estimates are used as indices of population size because they represent a directly observable/countable section of the population and comparable data are available for the grey seal populations in each of the range states. Total population estimates are derived from population dynamics models fitted to time series of pup productions in the two largest populations, i.e. Canada and the UK (Hammill *et al*., 2017; Thomas *et al*., 2011, 2019). However, although the models are similar, the published total population estimates are derived differently: in the Canadian population, total population refers to the number of 1+ age class animals alive at the end of the breeding season plus the total pup production for that year; in the UK the total population is given as the total number of seals alive at the start of the breeding season, i.e. does not include any of that year's pup production. The published estimates therefore differ by around 20 to 30% for the same pup production estimate. It is not clear how the total population is derived in several populations. To avoid confusion, only the pup production values are presented here.

Current status of British harbour seals

Harbour seals are counted while they are on land during their August moult, giving a minimum estimate of population size. Not all areas are counted every year, but the aim is to cover the UK coast every 5 years. The estimated total population for the UK and Northern Ireland in 2019 was 44,100 (approximate 95% CI: 36,100-58,800). This is derived by scaling the most recent composite count of 31,744, (based on surveys between 2016 and 2019) (Table 4) by the estimated proportion hauled out during the surveys (0.72 (95% CI: 0.54-0.88)). Overall, the UK population has increased since the late 2000s and is close to the 1990s level. However, there are significant differences in the population dynamics between regions. As reported in SCOS 2008 to 2018, there have been general declines in counts of harbour seals in several regions around Scotland, but the declines are not universal with some populations either stable or increasing.

Recent trends, i.e. those that incorporate the last 10 years show significant growth in both SMUs on the east coast of England up to 2018, but the 2019 count was approximately 25% lower than the mean of the previous 5 years in the large SE England SMU. Populations in Orkney & North Coast SMU and in the Tay and Eden SAC are continuing to decline and in Shetland and the Moray Firth, the current population size is at least 40 % below the pre-2002 level with no indication of recovery. Populations in western Scotland are either stable or increasing. In Northern Ireland counts have declined slowly.

Each year SMRU carries out surveys of harbour seals during the moult in August. Recent survey counts and overall estimates are summarised in SCOS-BP 20/03. Given the length of the mainly rocky coastline around north and west Scotland it is impractical to survey the whole coastline every year but SMRU aims to survey the entire coast across 5 consecutive years. However, in response to the observed declines around the UK the survey effort has been increased and some regions, e.g., Orkney and the Moray Firth have been surveyed more frequently. The English population and Scottish east coast populations in the Moray Firth, and the Tay and Eden estuaries are surveyed annually.

Seals spend a higher proportion of their time on land during the moult than at other times and counts during the moult are thought to represent the highest proportion of the population with the lowest variance. Initial monitoring of the population in East Anglia in the 1960s used these maximum counts as minimum population estimates. In order to maintain the consistency of the long-term monitoring of the UK harbour seal population, the same time constraints are applied throughout, and surveys are timed to provide counts during the moult. Most regions are surveyed using combined thermographic, video and HR still aerial imagery to identify seals along the coastline.

However, conventional photography is used to survey populations in the estuaries of the English and Scottish east coasts.

The estimated number of seals in a population based on these methods contains considerable levels of uncertainty. A large contribution to uncertainty is the proportion of seals not counted during the survey because they are in the water. Efforts are made to reduce the effect of environmental factors by always conducting surveys within 2 hours of low tides that occur between 10:00 and 20:00 during the first three weeks of August and only in good weather[2]. A conversion factor of 0.72 (95% CI: 0.54-0.88) to scale moult counts to total population was derived from haulout patterns of harbour seals fitted with flipper mounted ARGOS tags (n=22) in Scotland (Lonergan *et al., 20*13)

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

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

Location	Most recent count (2016-2019)	Total Population estimates with 95% CIs	
England	**3,900**	**5,400**	**(95% CI 4,400-7,200)**
Wales	**<10[1]**	**<15**	
Scotland	**26,800[2]**	**37,200**	**(95% CI 30.400-49,600)**
Northern Ireland	**1,000**	**1,400**	**(95% CI 1,100-1,900)**
Total UK	**31,700**	**44,000**	**(95% CI 36,000-58,700)**

[1] *There are no systematic surveys for harbour seals in Wales*
[2] *Compiled from most recent surveys (2016-2019), see Table 5 for dates and details*

The most recent counts of harbour seals by region are given in Table 5 and Figures 4, 5 & 6. These are minimum estimates of the British harbour seal population. Results of surveys conducted in 2019 are described in more detail in SCOS-BP 20/03. It has not been possible to conduct a synoptic survey of the entire UK coast in any one year. Data from different years are grouped into recent, previous and earlier counts to illustrate, and allow comparison of, the general trends across regions. Combining the most recent counts (2016-2019) at all sites, approximately 31,700 harbour seals were counted in the UK: 84.6% in Scotland; 12.3% in England; 3.1% in Northern Ireland (Tables 4 & 5). Including the 4,000 seals counted in the Republic of Ireland produces a total count of ~35,800 harbour seals for the British Isles (i.e. the UK and Ireland).

Apart from the population in the Southeast England SMU, harbour seal populations in the UK were relatively unaffected by phocine distemper virus (PDV) in 1988. The apparent, overall effect of the 2002 PDV epizootic on the UK population was even less pronounced. Again, the English east coast

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

populations were most affected, but the decrease was more gradual than in 1988, and the counts continued to decline for four years after the epizootic. Then, between 2006 and 2012 the counts approximately doubled in The Wash and increased by 50% for East Anglia as a whole. Since 2012 the counts in these areas have been almost constant until 2019 when they fell by approximately 25%.

Breeding season aerial surveys of the harbour seal population along the east Anglian coast are attempted annually, in addition to the surveys flown during the moult in August. In 2015 and 2016 the east Anglian coast was surveyed five times during the breeding season in June and July (Thompson *et al.,* 2016). These flights confirmed that the peak number of pups ashore occurred around the beginning of July. Due to a combination of aircraft availability and poor weather conditions no breeding season surveys were flown in the UK in 2019. Unfortunately, covid related travel and working restrictions also prevented survey flying in July 2020. Therefore, the most recent survey was carried out over two days, 29th June and 2nd July 2018. The 2018 count was 17% higher than the 2017 count and similar to the average for the preceding 5 years. This continues the pattern of high inter annual variability (SCOS-BP 19/04). These wide fluctuations are not unusual in the long term time series and despite the apparently wide inter-annual variation, the pup production has increased at around 5.6% p.a. since surveys began in 2001 although the rate of increase may have slowed and may be reaching an asymptote (SCOS-BP 19/04).

The ratio of pups to the moult counts remained high in 2018, more than double the same ratio in 2001. This ratio can be seen as an index of the productivity of the population. Until recently, the index for the Wash was higher than for the larger Wadden Sea population. However, the ratio has increased rapidly in the Wadden Sea population since 2008 as moult counts stopped increasing while pup counts continue to grow and the ratio is now at a similar level to the Wash population (Galatius *et al.,* 2020). Previous attempts to explain the apparently high fecundity/productivity in the Wash as being due to seasonal movements between these populations can no longer explain the increase. If the change is real, it suggests that either the fecundity has increased in both the Wash and Wadden Sea populations or that the ratio between the moult counts and the total population has changed. We do not have any information to determine the extent to which either of these metrics has changed. SCOS recommends further investigation to identify the underlying changes.

Table 5. *The most recent August counts of harbour seals at haul-out sites in the British Isles by Seal Management Unit compared with four previous periods.* The grey values given for SMUs 10-13 are rough estimates. *Details of sources and dates of surveys used in each compiled regional total are given in SCOS-BP 20/03.*

Seal Management Unit / Country			Harbour seal counts 1996-1997	2000-2006	2007-2009	2011-2015	2016-2019
1	Southwest Scotland		929	623	923	1,200	1,709
2	West Scotland	[a]	8,811	11,666	10,626	15,184	15,600
3	Western Isles		2,820	1,920	1,804	2,739	3,532
4	North Coast & Orkney		8,787	4,388	2,979	1,938	1,405
5	Shetland		5,994	3,038	3,039	3,369	3,180
6	Moray Firth		1,409	1,028	776	745	1,077
7	East Scotland		764	667	283	224	343
SCOTLAND total			29,514	23,330	20,430	25,399	26,846
8	Northeast England	[b]	54	62	58	91	79
9	Southeast England	[c]	3,222	2,964	3,952	4,740	3,752
10	South England	[d]	10	15	15	25	40
11	Southwest England	[d]	0	0	0	0	0
12	Wales	[d]	2	5	5	10	10
13	Northwest England	[d]	2	5	5	5	5
ENGLAND & WALES total			3,290	3,051	4,035	4,871	3,886
NORTHERN IRELAND total		[e]		1,176	1,101	948	1,012
UK total				27,557	25,566	31,218	31,744
REPUBLIC OF IRELAND total		[f]		2,955		3,489	4,007
BRITAIN & IRELAND total				30,512		34,707	35,751

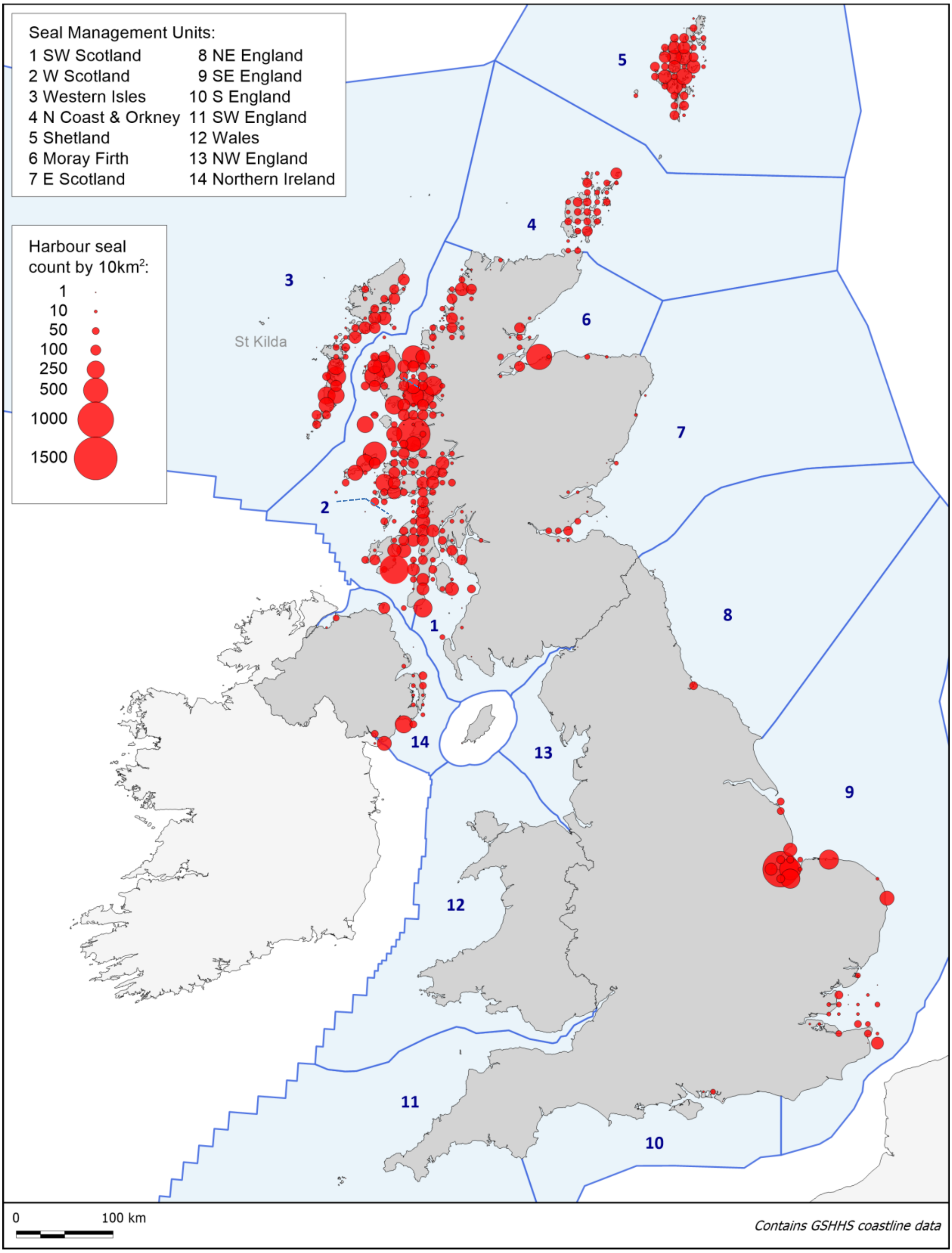

Figure 4. *August distribution of harbour seals around the British Isles by 10km squares based on the most recent available haul-out count data collected up until 2019. Limited data available for SMUs 10-13; no data available for St Kilda.*

Population trends

The overall UK harbour seal population has increased over the last decade. Counts increased from 25,600 (rounded to the nearest 100) in the 2007-2009 period to 31,700 during the 2016-2019 period. As no count was available in Northern Ireland in the 1990s, a UK wide comparison is not possible, but the 2016-2019 count of 31,700 harbour seals in Great Britain (i.e., UK minus Northern Ireland) was similar to the 1996-97 count of 32,800 (Table 5). However, as reported in SCOS 2008 to 2019, patterns of changes in abundance have not been universal; although declines have been observed in several regions around Scotland some populations appear to be either stable or increasing (Figure 5).

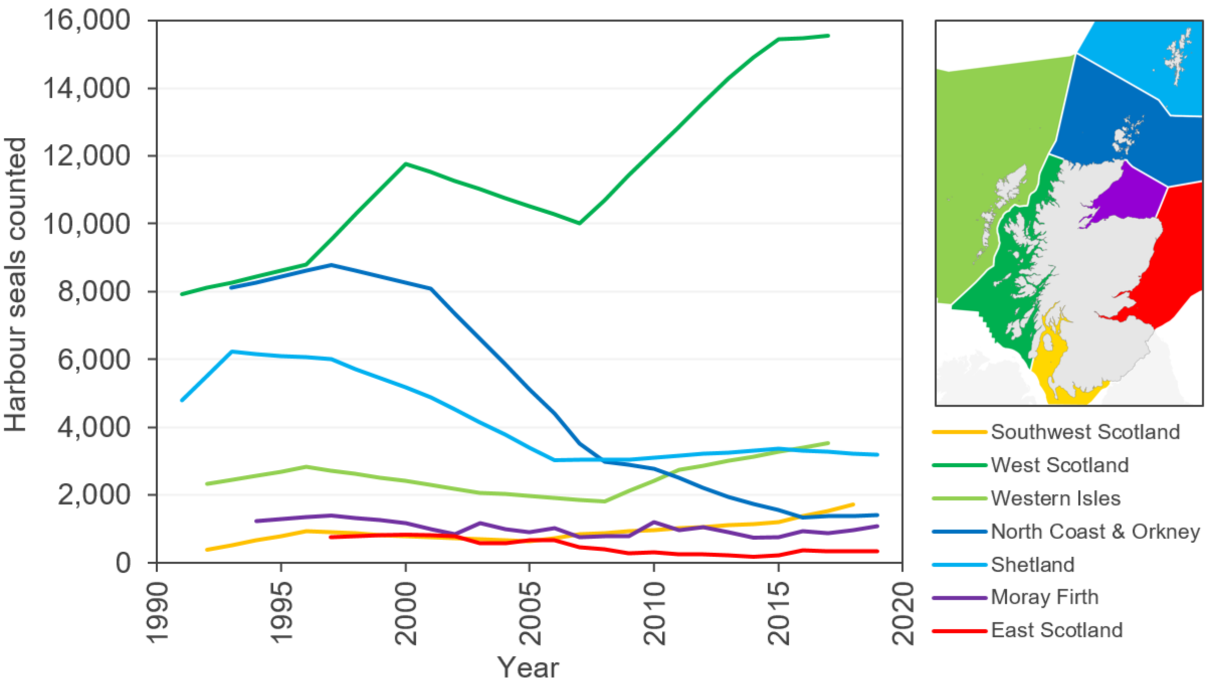

Figure 5. *Comparison of August harbour seal counts in Scottish Seal Management Units (SMUs) from 1991 to 2019. Because SMA totals represent counts of seals distributed over large areas, individual data points may contain counts made in more than one year. Interpolated values are used for years with incomplete coverage.*

***Trends by Seal Management Unit* (SMU).**

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

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

West Scotland: Parts of the West Scotland SMU (North and part of Centre) were surveyed in 2017 and the remainder was surveyed in 2018. The harbour seal count for West Scotland - North was

1,084, for West Scotland - Centre was 7,447 and for West Scotland – South was 7,053, and the overall total for the West Scotland SMU was 15,600 (Table 5).

The 2015 West Scotland harbour seal count was 43% higher than the 2009 count, equivalent to an average annual increase of 5.3%. However, as in the Western Isles, the data were best fitted by a simple intercept only GLM for the period from the 1990s to 2015, implying no significant change. The composite 2017-18 count is similar to the 2015 count.

Although the West Scotland region is defined as a single management unit, it is very large geographically in terms of total coastline and contains a large proportion of the UK harbour seal population; 49% of the most recent UK total count. The trajectories of counts within north, central and south sub-divisions of this large region differ (Thompson *et al., 20*19):

- In the north of the region (Figure 4), the selected model for data up to 2017 indicates that counts have increased since the early 1990s, by 4.9% p.a. (95% CI: 4.02, 5.70).

- In the central sub-region (Loch Ewe to Ardnamurchan) (Figure 4) the selected model for data up to 2014 indicates that counts have increased since the early 1990s, by 4.0% p.a. (95% CIs: 3.1, 5.0). The composite 2017-2018 count is consistent with a continued 4% p.a. increase. However, the selected model for the Ascrib, Isay and Dunvegan SAC counts, which extend to 2017, was an intercept only GLM implying no detectable trend since the early 1990s.

- In the south sub-region (Ardnamurchan to Scarba) (Figure 4) there was no detectable trend in the overall population since the early 1990s, with counts varying between approximately 5,000 and 7,000 over the period 1990 to 2018. Counts for both the Southeast Islay Skerries SAC and the Lismore SAC have also remained stable over the same period.

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

North Coast and Orkney: Orkney was surveyed twice during the last round-Scotland census period. In 2016, 1,240 harbour seals were counted, and 1,296 in 2019 (Table 5). These are the two lowest counts to date, around 85% lower than the highest count in 1997 (8,522). The 2016 and 2019 counts were similar. Although this could indicate that the decline has slowed this cannot be confirmed without additional counts. The 2016 and 2019 counts are >30% lower than the 2013 count, equivalent to an average annual decrease of between 6% and 10% p.a. Trend analysis (Thompson *et al*., 2019) indicates that counts were stable until 2001, that the next count in 2006 showed a decline of 46% and that from 2006 onwards, there was a continued decline of 10.4% p.a. (95% CIs: 9.3, 11.5) to 2016. Overall, the composite counts for the North Coast & Orkney SMU have declined from approximately 8800 in the mid-1990s to 1350 by 2016 (Table 5) representing an 85% decrease in what was the largest single SMU population in the UK. The North Coast section of the SMU was not surveyed in 2019 but few harbour seals are counted on the north coast section of the SMU.

The counts for the Sanday SAC show a similar trend, with a step change between 2001 and 2006 and a continuing declining at 17.8% p.a. (95% CIs: 13.3, 22.0) since 2006, by 2019 the Sanday SAC had declined by 95% from its maximum level in 1996-1997 (SCOS-BP 20/05).

Shetland: A complete survey was carried out in 2019 when 3,180 harbour seals were counted compared with 3,369 in 2015. The 2019 count was close to the mean of the 2009 and 2013 counts but was 47% lower than the 1997 count of c.6,000. The selected model for counts for the whole of Shetland incorporated a step change involving a drop of approximately 40% occurring between 2001 and 2005. Counts either side of the step change (1991-2001 and 2006-2019) do not show any obvious trend, though in both cases the sample size was limited (n=4 and 4, respectively).

Counts at the two Shetland SACs show different trajectories. The Mousa SAC counts show a monotonic exponential decline at an average rate of 11.1% p.a. (95% CIs: 8.7, 13.5) between 1991 and 2015 and that decline has continued at a similar rate (SCOS-BP 20/05). In contrast, an intercept only model was selected to fit the counts (1991-2015) of the Yell Sound SAC. However, including only counts between 1995 and 2015 (i.e. excluding 1991 and 1993), the selected model showed a decline of 5.3% p.a. (95% CIs: 2.6, 7.9). The 2019 count was slightly higher than the 2015 count (SCOS-BP 20/05)

Moray Firth: The total harbour seal count for the entire Moray Firth SMU in 2019 was 1025. This was 12% higher than the 2018 count. The majority of these harbour seals (60%) were observed between Culbin and Findhorn, confirming the continued importance of these sites and the dramatic and continuing redistribution within the inner Moray Firth.

The majority of the counts in the Moray Firth are from haul outs between Loch Fleet and Findhorn an area that held approximately 98% of the SMU total in 2016. The selected model for this area shows that counts were decreasing at a rate of 5.6% p.a. (95% CIs: 2.5, 8.5) between 1994 and 2000, followed by a step change with a drop of c.28% occurring between 2000 and 2003 and no significant trend in counts thereafter. Counts in 2018 and 2019 are consistent with a relatively stable population. Counts of harbour seals within the Dornoch Firth and Morrich More SAC have shown a monotonic decline of c. 8.0% p.a. (95% CIs: 6.3, 9.7) from the first surveys in 1992 to 2019.

East Scotland: The harbour seal count for the Firth of Tay and Eden Estuary SAC in 2019 was 41, equal to the mean of the previous 5 years' counts for this SAC. This represents a 94% decrease from the mean counts recorded between 1990 and 2002 (641).

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

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

The sporadic counts in the Firth of Forth indicate that the decline is localised within the SAC and may not represent the trends in the overall SMU population which may not be declining as rapidly. This highlights the need to obtain a series of counts of the harbour seal population in the Firth of Forth to properly assess the status of the SMU.

Northern Ireland: Only three synoptic surveys have been carried out of the entire harbour seal population in Northern Ireland. However, a subset of the population from Carlingford Lough to Copeland Islands has been monitored more frequently from 2002 to 2018. This area contained 80-85% of the total in the two years with complete coverage. This subset of the population declined slowly over the period 2002 to 2011 at an average rate of 2.7% p.a. (95% CIs: 1.8, 3.5). However, the 2018 survey suggests that there has been no significant change since.

South east England: The combined counts for the Southeast England SMU (Figure 6) in 2019 (3,081) was 27.6% lower than the 2012 to 2018 mean count. The scale of this drop is surprising, but no signs of disturbance were detected and weather and flying conditions were good. Such large scale drops in counts are usually associated with clear signs of disturbance and are excluded from analysis. However, a similar magnitude single survey decrease was recorded in 2010 without indications of weather or anthropogenic causes. The fact that the 2019 decrease follows a period when growth rates had decreased to zero, possibly indicating that the population in SE England SMU was approaching its carrying capacity means that it may be the first indication of a population decline. Further surveys in 2020 will help confirm the population's status.

The combined counts for The Wash, Donna Nook and Blakeney Point, taken here to represent the Southeast England SMU, are available from 1988 to 2019. The 1989 count was approximately 50% lower than the pre-epizootic count in 1988. The selected model in the trend analysis for the SMU incorporated two periods of exponential increase; 6.6% p.a. (95% CIs: 5.3, 7.9) between 1989 and 2002 and 2.8% p.a. (95% CIs: 1.3, 4.3) between 2003 and 2018. These periods of exponential increase were separated by a step change decrease of approximately 30% between 2002 and 2003 coincident with the second PDV epizootic. Although an exponential increase from 2003 to 2017 was marginally preferred by model selection there was an indication of a non-linear trend with a constant abundance followed by an increase and finally a levelling off in recent years. The 2019 count was 27% lower than the previous counts and if confirmed by further counts will suggest a major decrease in population.

The longer time series of counts for The Wash was best described by three distinct trajectories (Figure 6). From 1968 until 1988, the moult counts increased exponentially at 3.5% p.a. (95% CIs: 2.3, 4.76) reaching an estimated maximum count of c.3,000 (95% CIs: 2500, 3500) in 1988. The counts then fell by approximately 50% between 1988 and 1989 as a result of a PDV epizootic. This collapse was followed by a second period of exponential increase, but at a higher rate of 6.0% p.a. (95% CIs: 4.2, 7.8), with counts reaching c.3100 (95% CIs: 2800, 3350) by 2002 before a recurrence of the PDV epizootic caused another decrease. The counts from 2003 to 2017 are best described by a Generalised Additive Model (GAM) that initially estimates a decreasing trend until around 2006, increases rapidly until around 2010 and then levels off, suggesting that the population is approaching an asymptote (Thompson *et al.*, 2019).

The 2018 count was the second highest ever recorded in the Wash and was consistent with the pattern of relatively stable population since 2010. However, the 2019 count was 27% lower than the 2012 to 2018 mean count and a preliminary examination of the 2020 survey images produced a similar estimate to the 2019 count. Notwithstanding the variability associated with the proportion of the population hauled out and thus available to count, it seems likely that these lower counts represent a real decrease. The level of decrease and trajectory is unclear, but it represents a fall of approximately 10%-12% per annum over the two years, or around 25% between 2018 and 2019. Given that the survey area represents the majority of harbour seals in the South East England Seal Management Unit (SEE-SMU), including the population in the Wash & N Norfolk SAC, this likely drop in abundance is of immediate and serious concern. The SEE-SMU was the only one in the UK that was showing a sustained increase in abundance at a time when the majority of SMUs on the eastern and northern coasts had depleted or declining populations (Thompson *et al*., 2019; SCOS, 2020). SCOS recommend that research is required to determine the time course and potential causes of this reduction and recommend that SMRU should seek funding to establish an appropriate programme of research.

The Thames population, here taken to include all haulout sites between Hamford Water in Essex and Goodwin Sands off the Kent coast, have been surveyed sporadically since 2002 and annually since 2008. In August 2019 a total of 671 harbour seals were counted compared with an average of 742 for three surveys in 2016-2018, and an average of 474 for three surveys in 2013-2015. A GLM for the series of counts from 2002 to 2019 demonstrated an increase at an average of 9.0% p.a. (bootstrap 95% CI 6.8-11.2) (Cox *et al*., 2020).

Although the Southeast England population increased after the 2002 PDV epizootic, and has apparently levelled off at a similar size to its pre-2002 epizootic population, it grew at a much lower rate than the Wadden Sea harbour seal population, the only other major population in the southern North Sea. Counts in the Wadden Sea increased from 10,800 in 2003 to 26,788 in 2013, equivalent to an average annual growth rate of 9.5% over ten years. Counts since 2014 indicate that the rapid growth since the 2002 PDV epizootic has stopped (Galatius *et al*., 2019 & 2020). Although there was an influenza-A epizootic that killed at least 1600 seals in 2014 it now seems highly likely that cessation of the previously rapid increase in the Wadden Sea population indicates that it has reached its carrying capacity. The coincidence of the timing of the slowdown in the Wadden Sea and SE England is notable.

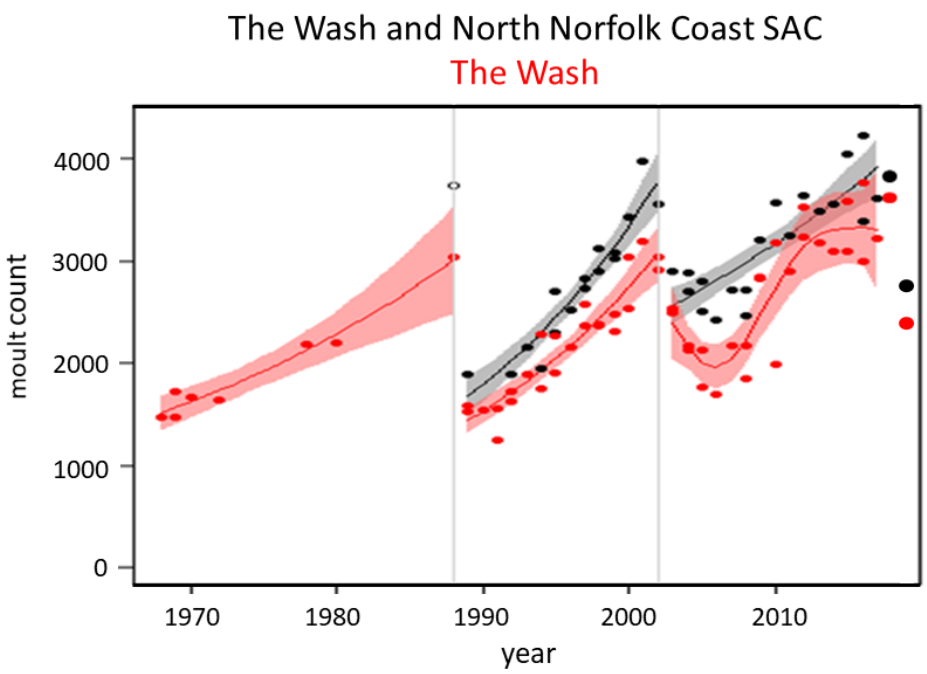

Figure 6. *Trends in harbour seals counts in The Wash (red) and the combined Wash and North Norfolk SAC, between 1967 and 2017 (shaded areas indicate the 95% confidence intervals for the fitted curves). For further explanation see text and Thompson et al. (2019). 2018 counts were similar to the previous 5 year's counts, but the 2019 count was approximately 27% lower.*

UK harbour seal populations in a European context

The UK harbour seal population represents approximately 32% of the eastern Atlantic sub-species of harbour seal (Table 6). Since 2000, the declines in Scotland and coincident dramatic increases in the

Wadden Sea mean that the relative importance of the UK harbour seal population has declined, although with the reduction in growth rates in the Wadden Sea this pattern may have stabilised.

Table 6. *Size and status of European populations of harbour seals. Data are counts of seals hauled out during the moult.*

Region	Number of seals counted[1]	Years when latest data was obtained
Scotland	**26,850**	2016-2019
England	**3,900**	2019[2]
Northern Ireland	**1,000**	2018
UK	**31,750**	
Ireland	4,000	2017-18
France	1,100	2018
Wadden Sea-Germany	18,450	2020
Wadden Sea-Denmark	2,250	2020
Wadden Sea-NL	7,700	2020
Delta-NL	950	2017
Limfjorden	1,050	2019
Kattegat	9,900	2019
Skagerrak	7,300	2019
Baltic (Kalmarsund)	1,800	2019
Baltic Southwestern	1,100	2019
Norway	6,800	2011-18
Svalbard	1,900	2010
Iceland	7,700	2016
Europe excluding UK	**68,100**	
Total	**99,850**	

[1] Counts rounded to the nearest 50. They are minimum estimates of population size as they do not account for proportion at sea and in many cases are amalgamations of several surveys.

[2] Includes an estimate of 55 seals for south England, Wales and north-west England compiled from sporadic reports

Data sources

ICES. 2020. Report of the Working Group on Marine Mammal Ecology (WGMME) , ICES Scientific Reports. 2:39. 85 pp. http://doi.org/10.17895/ices.pub.4980 . 120 pp; Desportes,G., Bjorge,A., Aqqalu, R-A and Waring,G.T. (2010) Harbour seals in the North Atlantic and the Baltic. NAMMCO Scientific publications Volume 8; Nilssen K, 2011. Seals – Grey and harbour seals. In: Agnalt A-L, Fossum P, Hauge M, Mangor-Jensen A, Ottersen G, Røttingen I,Sundet JH, and Sunnset BH. (eds). Havforskningsrapporten 2011. Fisken og havet, 2011(1).; Härkönen,H. and Isakson,E. 2010. Status of the harbour seal (*Phoca vitulina*) in the Baltic Proper. NAMMCO Sci Pub 8:71-76.; Olsen MT, Andersen SM, Teilmann J, Dietz R, Edren SMC, Linnet A, and Härkönen T. 2010. Status of the harbour seal (*Phoca vitulina*) in Southern Scandinavia. NAMMCO Sci Publ 8: 77-94.; Galatius A., Brackmann J., Brasseur S., Diederichs B., Jeß A., Klöpper S., Körber P., Schop J., Siebert U., Teilmann J., Thøstesen B. & Schmidt B. (2020) Trilateral surveys of Harbour Seals in the Wadden Sea and Helgoland in 2020. Common Wadden Sea Secretariat, Wilhelmshaven, Germany. ; Härkönen T, Galatius A, Bräeger S, *et al.*,HELCOM Core indicator of biodiversity Population growth rate, abundance and distribution of marine mammals, HELCOM 2013, www.helcom.fi; www.fisheries.is/main-species/marine-mammals/stock-status/; www.nefsc.noaa.gov/publications/tm/tm213/pdfs/F2009HASE.pdf; www.hafogvatn.is/en/research/harbour-seal/harbour-seal-census. www.nammco.no/webcronize/images/Nammco/976.pdf, Nilssen K and Bjørge A 2017. Seals – grey and harbor seals. In: Bakketeig IE, Gjøsæter H, Hauge M, Sunnset BH and Toft KØ (eds). Havforskningsrapporten 2014. Fisken og havet, 2014(1). Merkel,B., Lydersen,C, Yoccoz,N. & Kovacs, K. (2013)The World's Northernmost Harbour Seal Population–How Many Are There? *PLOS-ONE*. https://doi.org/10.1371/journal.pone.0067576

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

The most recent survey data and descriptions of trends in harbour seal counts for all SACs in Scotland and England are presented in SCOS-BP 20/05 and briefly described in answer 1 above. Grey seal pup production estimates and descriptions of trends at all SACs in Scotland and England are presented in Russell *et al*. (2019).

Harbour seals.
Information on the available data, trend analyses and comparisons with survey data for adjacent areas up to 50km from the SAC together with similar data and analyses for all SMUs in Scotland form part of a report to NatureScot that will be published in 2021. For information the SAC relevant sections of that report have been summarised in SCOS-BP 20/05. Trend analyses are presented in Thompson *et al*. (2019) and briefly described in answer 1 above.

Dynamics of SAC populations of harbour seals vary (see SCOS-BP 20/05 and answer 1 above). Comparisons of the time series of harbour seals counted within SACs compared with numbers found within a 50km range show that SACs are not reliable indicators of trends in the wider population. This is especially evident for the Sound of Barra SAC, where harbour seal numbers have declined dramatically since the 1990s. In contrast, surrounding areas have seen a significant increase in numbers. To varying degrees, all SACs now represent a smaller proportion of the wider population than in the past.

Recent counts in the Wash and North Norfolk SAC show a dramatic reduction. The 2019 count was 27% lower than the preceding 5-year average. Preliminary results from 2020 suggest that this was a real decrease. SCOS have highlighted this population as a priority for additional research and increased monitoring.

Grey seals
A small number of grey seal breeding sites are designated as SACs and use pup production as a condition indicator. Trends in pup production in those SACs were described by Russell *et al.* (2019) and are briefly described here.

Treshnish Isles SAC (Inner Hebrides) produced over a third of the pups born in the Inner Hebrides in the late 1980s. Until the mid-1990s, the trend in pup production within the Treshnish Isles SAC mirrored the regional trend, after which pup production in the SAC showed indications of a gradual decline. From 2010 to 2016, the SAC produced approximately 25% of pups born in the Inner Hebrides.

Monach Isles SAC (Outer Hebrides) produced 79% of the pups born in the Outer Hebrides in 2016. As a consequence, the Outer Hebrides pup production trend closely mirrors the trend seen at Monach Isles which showed an increase of 7.4% p.a. (CIs: 6.3, 8.4) between the mid-1980s and mid-1990s before levelling off as the pup production approached an asymptote.

North Rona SAC, (Outer Hebrides) used to be the biggest colony in the Western Isles (c. 2,000 pups in 1960s and 1970s), but has declined since 1995 at a rate of 5.1% p.a. (1995- 2010: CIs: 4.2, 6.0), with fewer than 400 pups born in 2016 Many of the other historical colonies in the

Outer Hebrides underwent similar decreases in pup production (e.g. Causamul: -8% p.a. (CIs: 6.8, 9.3); Haskeir: 3.3% p.a. (CIs: 2.4, 4.1)). More recently, Gasker also declined (-4% p.a. (2000-2010; CIs: 387 2.7, 5.3)). Conversely, newly established colonies (e.g. Berneray, Mingulay and Pabbay) in the south of the region increased.

Faray & Holm of Faray SAC (Orkney) produced approximately 15% of the pups born in Orkney in 2016. Pup production within the Faray & Holm of Faray SAC increased at a rate of 9.4% p.a. (1987-1995; CIs: 7.5, 1.4) reaching a maximum of 3,840 pups in the late 1990s before decreasing at a rate of 2% p.a. since 2000 (CIs: 0.8, 3.2). Production in Orkney reached an asymptote of 18,000 to 19,000 pups in c.2000 and has been stable ever since.

Isle of May SAC (East Scotland) The pup production in the central North Sea has increased since 1987 at an average rate of 5% p.a. between 1987 and 2010 (CIs: 4.4, 5.5). However, rates of increase at the three main colonies vary. Production at the Isle of May increased exponentially at 9.9% p.a. (CIs: 7.5, 12.3), since surveys began (1979), before reaching an asymptote of c.2,000 pups in the late 1990s.

Berwickshire and North Northumberland Coast SAC (East Scotland & Northeast England). Pup production in the Berwickshire & North Northumberland Coast SAC is continuing to increase and does not show any indication of reaching an asymptote. However, this SAC contains two large, discrete grey seal breeding populations with different histories and different recent dynamics. The Farne Islands have been an important breeding site since the middle ages while Fast Castle is a recently established breeding site first colonised in the 1990s. Pup production at the Farne Islands increased from the beginning of the surveys in the 1950s until the mid-1970s, when production fell rapidly likely due to a series of culls (Summers, 1978) between 1967 and 1985 (pre-cull pup production between 1956-1965: 7.5% p.a.; CIs: 6.5, 8.5). Production increased at a slower rate of 4.2% p.a. in recent years (2005 – 2014; 95% CIs: 3.2, 5.2).
The Fast Castle colony has continued to increase at a rate of 16.9% p.a. (CIs: 15.2, 18.7).

Pembrokeshire Marine/ Sir Benfro Forol SAC. Pup production at Skomer, on the Marloes Peninsula and at the monitored sites on Ramsey Island have all increased (see SCOS-BP 20/04 for details and data sources). This increase persists despite significant bycatch that exceeds current PBR estimates for the wider SW British Isles population of grey seals (see answer 11 & 14 for detailed discussion).

3. Can SCOS provide pup production and population estimates separately for a range of smaller units which we can combine to inform putative Management Units? (Wales, The Irish Sea, The Celtic Sea (SW approaches including SW England, Wales and South and SE Ireland, East coast Ireland, West coast Ireland, West Coast Scotland as well as separately for each ICES area: each of 7a, 7g and 7f, 7b, 7j, 7h, 7e and 6a).	NRW Q3b

Generating the pup production estimates structured by the regions/areas requested has not been possible in the timeframe allowed.

To provide pup production and population estimates at the range of scales required to allow the definition of putative Management Units suggested in this question, we would require data additional to current SMRU holdings. In particular, there would be a requirement for pup production estimates from Ireland and Northern Ireland. A time series of pup production estimates for Irish colonies should be available by summer 2021, SMRU will investigate the possibility of incorporating Northern Irish grey seal pup production data in future SCOS reports. The ability to currently incorporate existing data from the SW of the UK (SW England and Wales) in SMRU's population models is discussed in SCOS-BP 20/04. Biennial grey seal pup production estimates are available however for all regularly monitored colonies in the West Scotland SMU, these colonies represent over >96% of the pup production in that SMU.

The current management units are shown in Figure 4 and the justification for their selection is presented in answer 11a below along with a discussion of the issues associated with coalescing SMUs to provide larger PBRs for widespread issues. The main problem is the potential for the management to be less sensitive to impacts at local scales by assessing their population effects on larger population units.

The boundaries of the current SMUs were set for a number of pragmatic reasons (described in answer 11 below). There would appear to be no more justification for selecting the boundaries of ICES statistical areas and sub-units than the more pragmatic selections based to some extent on monitoring capabilities and management jurisdictions.

4. Can SCOS committee review and advise on most robust methods/terminology for grey seal pup ground counts currently used to understand whether recent work (funded by NE) would be suitable for possible future inclusion in population estimate modelling?? **In Wales, a number of key grey seal pupping sites are counted annually (Skomer MCZ, Ramsey Island, Bardsey Island up until last year). What are the statistical reasons for not being able to incorporate these data into UK wide pup production models? Could/should the way in which data is collected here be changed to allow the data to be incorporated?**	Defra Q1b NRW Q1a

SCOS considers that the current survey data available for southwest UK would not be compatible with the SMRU pup production model. Alternative simple methods are suggested where appropriate.

The SMRU pup production model may be applicable to estimate pup production at some regularly monitored sites in Wales.

SCOS advises that monitoring indicator sites may be the most appropriate method for monitoring trends in grey seal pup production where a substantial proportion of the pups are difficult to count. However, to generate a robust time series, the scalar between such indicator sites and less regularly monitored sites needs to be periodically reviewed. SCOS considers that to generate a robust pup production estimate for Wales a comprehensive West Wales survey is required as the last such survey was conducted in the early 1990s.

Inclusion of pup production in the UK grey seal population model would require both a regular time series of pup production estimates and independent estimates equivalent to the August surveys around Scotland and in the North Sea.

The relatively small population in the SW England SMU means that inclusion as a simple additive correction to the UK population model is probably the most appropriate and cost-effective method.

The SMRU pup production model is run at the scale of the colony and is used for a subset of colonies which account for approximately 80% of UK pup production. Such colonies are, almost exclusively, aerially surveyed colonies. Estimating pup production within the model requires the estimation of a single birth curve and thus is not suitable for very small colonies or sparsely distributed pups as are often the case along stretches of coast in Wales and southwest England. The model also requires (1) four or more synoptic (single day) surveys, (2) Classified counts (Whitecoat vs Moulted Pups), and (3) information on observation parameters (probability of detecting and correctly classifying) pups.

More investigation would be required, but the current pup production model (or the new version currently under development) may be suitable for the Isles of Scilly and Lundy. Depending on survey frequency, classed counts (whitecoat and moulted counts) from the Isles of Scilly and Lundy could be input into the SMRU pup production, if that was deemed preferable to current methods. As the SMRU pup production model is not suitable for some colonies in Wales and southwest England, alternative simple methods are suggested.

For sites, where resources, conditions and seal density allow, following pups through a season is likely to be the most accurate measure of pup production. For other sites, counts of white coat pups at approximately 23-day intervals (mean age of becoming fully moulted), can be summed to estimate pup production, though producing associated uncertainty estimates is more difficult. SCOS-BP 20/04 provides a more detailed discussion of these issues.

Recent surveys conducted in mainland Cornwall have demonstrated that the majority of pups (>95%) can be surveyed from land, and thus surveying by boat is not necessary to produce robust estimates of pup production. The most appropriate methods of survey (direct observation vs drone) may be dependent on the site.

The frequency and intensity of survey effort required depends upon the aim of the monitoring programme. In Wales, if the aim is to generate a time series of pup production estimates for the whole country, then sites that are easier to monitor (indicator sites) could be used to estimate pup production (see SCOS-BP 20/04). However, to generate a robust time series, the scalar between such indicator sites and the less regularly monitored sites needs to be periodically reviewed. This is particularly important when the reasons for the different intensities of survey are related to the type of site. Cryptic sites (such as caves, small coves) will often support much smaller colonies and thus their trends, especially in the longer term, may differ from more open sites that are also easier to monitor. Indicator sites should be matched with less regularly monitored sites that are in the same area, and where possible, are similar type of site. For example, trends from a section of the mainland coast are likely to be more indicative of a whole stretch of coast than trends from a nearby beach. To generate robust up-to-date estimates of pup production for Wales, a comprehensive West Wales survey is required; the last such survey was conducted in the early 1990s.

At present the pup production estimates for Wales and SW England are not included directly in the population dynamics model for the rest of the UK but are included in the estimation of the overall population (see Q1). Including the pup production data for the Southwest England and Wales SMUs would require a regular time series of SMU-wide estimates of pup production but would also require a robust independent estimate (from August counts). The absence of independent estimates currently prevents such inclusion. Even with such independent estimates, the sparse time series of pup production estimates means that their inclusion would not enhance our understanding of the grey seal population in the southwest UK and may negatively affect the accuracy of the UK-wide population estimates. The relatively small population in this SMU means that inclusion as a simple additive correction to the UK population model is probably the most appropriate and cost-effective method. See SCOS-BP 20/04 for a more detailed discussion in response to this question.

5. Other sites occur in cryptic habitats such as sea caves and habitats that make detection of pups via aerial surveying problematic or are difficult to access during ground counts (by boat/foot/cliff top viewing). Would aerial/drone surveys potentially be a way forward given the obvious issues of not being able to cover cryptic sites?	NRW Q1b

The choice of survey method will be strongly influenced by the physical characteristics, accessibility, and scale of the breeding sites. Notwithstanding the operational limitations associated with the use of drones, they are likely to be of use for some indicator sites.

The choice of survey method will be strongly influenced by the physical characteristics, accessibility and scale of the breeding sites. Recent surveys in both North Wales and SW England, found that relatively few pups are born in caves, and thus the error associated with excluding caves in these areas is likely low (relative to other sources of error); surveying seals in caves is relatively expensive and can be dangerous, and is associated with high levels of disturbance. However, a substantial proportion of pups are born in caves in some areas (e.g. West Wales). The most suitable method is likely dependent on the site. On mainland Cornwall, <5% of pups were only counted during boat-based surveys (Sayer, Millward and Witt 2020) suggesting that land-based surveys are most appropriate for these areas. Boats may be required for some areas, for example, in North Wales. Drones may be suitable for some sites, though operation of commercial drones usually has to be within line of sight of the operator. Together with other distance restrictions and battery considerations, this limits their utility for larger colonies or stretches of coastline. Drones are currently used to monitor seals at South Walney in northwest England.

Structure of UK seal populations

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

Grey seals

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

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

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

Age and sex structure

While the population was growing at a constant (i.e. exponential) rate, it was assumed that the female population size was directly proportional to the pup production. Changes in pup production growth rates imply changes in age structure. In the absence of a population-wide sample or a robust means of identifying age-specific changes in survival or fecundity, we are unable to accurately estimate the age structure of the female population. An indirect estimate of the age structure, at least in terms of pups, immature and mature females is generated by the fitted population estimation model (SCOS-BP 20/01). As currently structured the model fits single global estimates for fecundity, maximum pup survival (i.e. at low population size), and adult female survival, and fits individual carrying capacity estimates separately for each region to account for differing dynamics through density dependent pup survival.

Survival and fecundity rates

The only contemporary data that we have on fecundity and adult survival in UK grey seals has been estimated from long term studies of marked or identifiable adult females at two breeding colonies, North Rona and the Isle of May. Results of these studies together with branding studies in Canadian grey seal populations and historical shot samples from the UK and Baltic have been used to define priors for a range of demographic parameters (SCOS-BP 20/02).

Adult female survival: Estimates of annual adult survival in the UK, obtained by aging teeth from shot animals were between 0.93 and 0.96 (Harwood & Prime, 1978; Hewer, 1964; SCOS-BP 12/02). Capture-mark-recapture (CMR) of adult females on breeding colonies (Smout *et al.*, 2019) has been used to estimate female survival on North Rona and the Isle of May of 0.87 and 0.95 (SCOS-BP20/02 - Table 2). The population dynamics models fitted to the pup production time series, produced estimates of adult female survival close to the upper limit of that range (SCOS-BP 20/01). Interestingly, recent estimates from Sable Island suggest that adult female survival during the main reproductive age classes (4 to 24 years old) may be even higher. A Cormack-Jolly-Seber model was used to estimate age- and sex-specific adult survival from a long-term brand re-sighting programme on Sable Island (den Heyer & Bowen, 2017). Average adult female survival was estimated to be 0.976 (SE 0.001), averaged over all animals, but was higher for younger adults (0.989 with SE 0.001 for age classes 4-24) than older adults (0.904 SE 0.004 for age 25+).

In the current population estimation model density dependence acts through pup survival only, so adult survival does not vary with time or between regions. The fitted posterior value for adult survival was a constant rate of 0.96 (SE 0.01).

***Fecundity*:** For the purposes of the population estimation model, fecundity is taken to be the proportion of breeding-age females (aged 6 and over) that give birth to a pup in a year (natality or birth rate). Pregnancy rates estimated from samples of seals shot in the UK (Hewer, 1964; Boyd, 1985) and Canada (Hammill & Gosselin, 1995) were similar, 0.83 to 0.94 and 0.88 to 1 respectively. However, these are pregnancy rates and may overestimate natality if there are significant numbers of abortions.

Natality rates estimated from direct observation of marked animals produce lower estimates, which may be due to abortions, but may also be due to unobserved pupping events (due to mark misidentification, tag loss, or breeding elsewhere) and may therefore under-estimate fecundity. Such studies, from Sable Island estimate fecundity to be between 0.57 and 0.83(den Heyer & Bowen, 2017; Bowen *et al., 20*06). UK estimates of fecundity rates adjusted for estimates of unobserved pupping events were higher; 0.790 (95% CI 0.766-0.812) and 0.816 (95% CI 0.787-0.841) for a declining (North Rona) and increasing (Isle of May) population respectively (Smout *et al.*, 2019).

In the current population estimation model, density dependence acts through pup survival only, so fecundity does not vary with time or between regions. The fitted posterior value for fecundity was 0.90 (SE 0.06) (SCOS-BP 20/01).

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

- Kauhala *et al.* (2019) used samples from seals shot in Finland to show that pregancy rate can fluctuate significantly (between c0.6 and c0.95) and are significantly related to herring (*Clupea harengus*) and sprat (*Sprattus sprattus*) quality (weight), which, in turn were influenced by sprat and cod (*Gadus morhua*) abundance and zooplankton biomass. Their results suggest strong trophic coupling over three trophic levels in the Baltic and suggest that this is likely to influence fecundity rates.
- Smout *et al.* (2019) reported a similar link between likelihood of breeding and environmental conditions during the preceding year.
- In a parallel study, Hanson *et al.* (2019) showed high levels of variation in individual postpartum maternal body composition at two grey seal breeding colonies (North Rona and Isle of May) with contrasting population dynamics. Although average composition was similar between the colonies, it increased at the Isle of May where pup production increased and declined at North Rona where pup production decreased.
- Badger *et al*. (2020) investigated the effects of increasing population density on the reproductive performance of female grey seals classed as high- and low-quality breeders. They showed that high quality females maintain their reproductive output as population density increased, while reproductive performance of poor-quality females declined.

All four studies suggest that fecundity or reproductive performance is influenced by prevailing environmental conditions. The consequences in terms of population level fecundity estimates are not clear, but SCOS recommends continued investigations into the effects of environmental variation on fecundity and the potential effects of such links on population projections for UK grey seal populations.

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

Estimates of maximum pup survival, from populations experiencing exponential growth and therefore presumed not to be subject to strong density dependent effects are given in SCOS-BP 20/02 (Table 2). Mean estimates of pup survival were between 0.54 – 0.76.

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

It is also possible to derive current pup survival estimates from the model. The posterior estimates of pup survival at current population sizes differ between regions. In the North Sea where density dependence is having little effect, the current pup survival estimate is 0.43, close to the maximum, unconstrained rate. In the other three regions where population growth has slowed or stopped the current estimate is much lower, being 0.11 in the Inner and Outer Hebrides and Orkney. Thomas *et al*., (2019) estimated that pup survival for a population at carrying capacity will be around 0.1-0.14.

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

den Heyer and Bowen (2017) estimated survival rates of male and female branded seals at Sable Island, Canada. The differential survival of males and females would produce an effective sex ratio of 1:0.7 if maximum age is set to 40, reducing to 1:0.69 if maximum age is set to 45. This estimate is remarkably similar to the prior used in the 2016 model runs.

Investigations using the grey seal population dynamics model suggested that changes in first year survival rather than changes in fecundity are the main mechanisms through which density dependence acts on UK grey seal populations (Thomas, 2010; Thomas *et al*., 2019). Fecundity at an increasing population at the Isle of May was only marginally higher than in a declining population at North Rona colony in Scotland, and fecundity has not changed as the Sable Island grey seal population reaches density dependent limits (den Heyer *et al.*, 2017; Smout *et al.,* 2019). Variation in fecundity may become increasingly important in areas where populations have reached carrying capacity, e.g., age of first recruitment appears to increase as populations reach carrying capacity (Bowen *et al.,* 2006) and the reproductive success of individuals becomes more variable (Badger *et al*., 2020).

Regional data on fecundity and survival rates would allow us to further examine the drivers of population trends. Such data would feed into the population dynamics model, improving confidence in model predictions and enhancing our ability to provide advice on population status. Furthermore, such data could inform effective management by identifying the relative sensitivities associated with different life stages, in terms of population dynamics. SCOS 2019 recommended that new resources should be identified to investigate regional patterns and the effects of environmental covariates on both first-year survival and fecundity in UK grey seal populations.

Regional differences in grey seal demographics and genetics

The difference in population trends between regions for UK grey seals suggests underlying regional differences in the current values of demographic parameters. On the basis of genetic differences there appears to be a degree of reproductive isolation between grey seals that breed in the south-west (Devon, Cornwall and Wales) and those breeding around Scotland (Walton & Stanley, 1997) and within Scotland, there are significant differences between grey seals breeding on the Isle of May and on North Rona (Allen *et al.,* 1995). There is therefore some indication of sub-structure within the UK grey seal population, but it is not strong.

Recent genetic data from the Baltic grey seals (Fietz *et al.*, 2016) suggest that a combination of previous management practices and local climate change effects may be moving the boundaries between the North Sea and Baltic subspecies of grey seal.

The very rapid increases in pup production at colonies in the Southern North Sea in England, the Netherlands and Germany all point to large scale recruitment to those colonies from colonies in the Northern North Sea (Brasseur *et al.*, 2015). Similar immigration appears to be driving growth in southern colonies on the west side of the Atlantic. On the basis of mDNA haplotype information Wood *et al.* (2011) could not differentiate between US and Canadian grey seal populations and concluded although grey seals are regarded as philopatric, their results indicate that the genetic structure of the northwest Atlantic grey seal population is not different from the null hypothesis of panmixia.

A PhD project based at the Galway-Mayo Institute of Technology (GMIT) is currently investigating the genetic structure of both grey and harbour seals occupying Irish haul-out sites and coastal/marine waters and their relationship to wider regional populations across Western Europe. The results of this study are intended to inform the possible identification of appropriate Assessment/Management Units for seals in Ireland. Results are expected to be available in time for SCOS 2022. A similar analysis of genetic structure in grey & harbour seals in Norway is underway but at an early stage.

Harbour seals

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

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

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

Age and sex structure

The absence of any extensive historical cull data or a detailed time series of pup production estimates means that there are no reliable data on age structure of the UK harbour seal populations.

Although seals found dead during the PDV epizootics in 1988 and 2002 were aged, these were clearly biased samples that cannot be used to generate population age structures (Hall *et al*., 2019).

Survival and fecundity rates

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

A study investigating first year survival in harbour seal pups, using telemetry tags was carried out in Orkney and on Lismore in 2007. Battery life of the transmitters limited the study duration, but survival was not significantly different between the two regions and expected survival to 200 days was 0.3 (Hanson *et al.*, 2013). Harding *et al.* (2005) showed that over winter survival in harbour seal young of the year was related to body mass and to water temperature. Estimates of survival and fecundity of harbour seals in Orkney and Skye should be available for SCOS 2021 from the ongoing harbour seal decline project.

In South-east England there is evidence for changing demographic parameters in harbour seals. The apparent fecundity, i.e., the peak count of pups (as an index of pup production) divided by the moult survey count (as an index of total population size) of the large harbour seal population in The Wash has shown large changes since the early 2000s. The rate has been approximately twice that of earlier estimates and until recently was much higher than in the larger population in the Wadden Sea (SCOSBP 20/03). The fact that apparent fecundity of the much larger population in the Wadden Sea has now also increased, suggests that this is a real effect and not due simply to movement between breeding and moulting populations in the two areas. This is a crude metric for the productivity of a population of seals and may be influenced by changes in the timing or the pattern of haulout during the moult. It does however indicate that demographic rates, or our indices of those rates, are changing and require further investigation.

Growth.

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

A comprehensive length-at-age dataset for UK harbour seals spanning 30 years, was investigated but showed no evidence for major differences, or changes over time in asymptotic length or growth parameters from fitted von-Bertalanffy growth curves, across all regions (Hall *et al.*, 2019). However, the power to detect small changes was limited by measurement uncertainty and differences in spatial and temporal sampling effort. Asymptotic lengths at maturity were slightly lower than published lengths for harbour seal populations in Europe, the Arctic and Canada, with females being on average 140.5cm (95% CI, 139.4, 141.6) and males 149.4cm (147.8, 151.1) at adulthood.

This lack of signal is in contrast to data from Danish and Swedish harbour seal populations. Comparison of somatic growth curves of 2,041 specimens with known age, length and population size at birth showed that while all populations were similar in 1988, by 2002 there were clear differences between populations (Harding *et al.*, 2018). While seals in the Kattegat showed similar asymptotic lengths as in 1988, seals in the Skagerrak were significantly shorter. Asymptotic lengths of both male and female harbour seals declined by 7 cm. The restricted growth may have been related to relative foraging densities of seals, which were three times greater in the Skagerrak compared to the Kattegat. The authors suggest that reduced growth in the Skagerrak may be an early signal of density dependence.

Genetics

Genetic data from a study directed toward resolving patterns of population structure of harbour seals from around the UK and adjacent European sites (Olsen *et al.*, 2017) has recently been added to (with funding from Scottish Natural Heritage) and combined with the population trend and telemetry data to investigate source-sink dynamics of harbour seal populations.

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

The UK harbour seal population can be divided into similar regional sub-divisions to those seen in the genetics data on the basis of the observed population trends. The southern UK population equivalent to the English east coast shows continual rapid increase punctuated by major declines associated with PDV epizootics in 1988 and 2002. Populations along the East coast of Scotland and in the Northern Isles have generally declined while populations in western Scotland are either stable or increasing.

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

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

Harbour Seal Decline

7. Is the existing harbour seal decline recorded in several local areas around Scotland continuing and what is the position in other areas?	MS Q4

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

The most recent composite count for Scotland, for surveys in 2016 to 2019, was 6% higher than for the previous round of surveys (2011-2015) and 31% higher than the 2007-2009 composite count.

Counts in Orkney in 2016 and 2019 were almost identical but are still consistent with a continuing decline. Firth of Tay and Eden counts indicate a continued decline. Counts in the Moray Firth and Shetland have apparently remained stable after experiencing large reductions around 2002. Counts also appear stable in the Western Isles and Southwest Scotland management units and are increasing in the north and central parts of the West Scotland SMU. The most recent count in the West Scotland management area is the highest to date.

The current UK harbour seal population is at a similar size to the estimates from the late 1990s, but there have been significant population declines in some regions and similar increases in others. As reported in previous SCOS reports since 2008, there have been general declines in the counts of harbour seals in several regions around Scotland, but the declines are not universal with some populations either stable or increasing. Details of trends are presented in SCOS-BP 20/03 and Thompson *et al. (*2019).

The composite count for all of Scotland, based on recent (2016-2019) surveys was 6% higher than for the previous round of surveys (2011-2015) and 31% higher than the 2007-2009 composite counts, representing approximately 3% p.a. increase (Figure 5; Table 5) and is similar to counts in the mid-1990s.

Trends by SMU are reported in answer 1 above and shown in Figure 5 for Scottish SMUs and Figure 6 for the Southeast England SMU. Briefly, the population in the Western Isles SMU appears to have remained stable since the 1990s. Populations in West Scotland and Southwest Scotland SMUs are now increasing. Shetland and the Moray Firth SMUs are apparently stable after a large rapid decline in the early 2000s. North Coast and Orkney SMU is still declining although the last two counts in 2016 and 2019 are equal. In the East Scotland SMU the population in the Tay and Eden SAC has declined rapidly since 2002 and the decline is apparently continuing. However, sporadic counts in the Firth of Forth indicate that the decline is localised within the SAC and may not represent the trends in the overall East Scotland SMU population which may not be declining as rapidly.

Large changes in relative density have resulted from differences in regional population trends. E.g. in 1996-1997 the West Scotland SMU and Orkney & North Coast SMU each held 27% of the UK population but now hold 50% and 4% respectively; The southeast England SMU population was approximately half that of the Wadden Sea in 1980 but by 2019 the Wadden Sea count was approximately eight times larger.

Given the variable patterns in harbour seal trends and very significant declines in some management units SCOS consider it prudent and timely to undertake risk assessments regarding the sustainability of local population in relevant SMUs. These should be based on available scientific knowledge (e.g. breeding data, movements, immigration, emigration). A further consideration would be to review resourcing, to ensure that adequate monitoring resources are deployed in SMUs considered “high risk” as a result of such an assessment exercise.

8. In the 2019 advice, SCOS provide a view on the current potential (major) drivers of the harbour seal decline and their status. Can SCOS provide an update on these now that some of the ongoing work streams have completed?	MS Q4

The causal mechanisms of the harbour seal decline have not been identified, but several factors have been excluded as primary causes of the decline, although these may remain as potential secondary causes. Table 7 contains a list of potential factors involved and the current assessment of their importance (modified from SCOS 2019). A few critical factors still remain which require further research, including reduction in prey availability, competition with grey seals for prey resources, predation by grey seals and by killer whales, and exposure to toxins from harmful algae.

The Sea Mammal Research Unit has been funded by the Scottish Government to investigate the causes of the declines. A summary of the progress and initial results of the programme are presented in SCOS-BP 20/06. Previous and recent work conducted during Phase II of this project (which was completed in early 2020) suggest that toxins from HABs may increase harbour seal mortality, based on a bio-energetic model estimating the range of likely daily toxin doses ingested by harbour seals. Phase III of the project will aim to increase the number of prey samples during HAB events to update the risk assessment approach and will compare data on toxin concentrations in prey between declining and non-declining sites. The project will continue to focus on the estimation of survival and fecundity rates at sites of contrasting population trajectories with an extended dataset (2016 to 2022 with a gap year for 2020 due to covid-19 pandemic). Two SUPER DTP funded projects started in 2019 and in 2020 which will address inter-species competition, the effect of grey seal predation on regional declines, and killer whale predation on harbour seals.

For information, Table 7 contains a list of potential drivers and the current assessment of their importance (modified from SCOS 2019). A confidence level (1-high, 2-medium, 3-low) has been added to each of the potential drivers to reflect uncertainty on the assessment of their importance in the observed declines based on the evidence available.

It is recognised that different factors may be implicated in the declines in different SMU populations and that there is no guarantee that the list in Table 7 is comprehensive. So far unidentified factors may be important in some SMUs.

Table 7. The current view of the potential factors and their likely importance as drivers of the observed declines in harbour seals in some areas (Orkney, East Coast, MF), with associated confidence level given the evidence (1 – high , 2 – medium, and 3 – low confidence level). Additional information in SCOS questions and/or BP is indicated.

Factor	Importance status	Confidence level	Evidence	Additional information
Competition with other marine predators	Possible	2	Competition for prey with the increasing grey seal population and/or other marine predators cannot be ruled out. A PhD project at SMRU to investigate evidence for inter-specific competition, started in 2019.	
Predation	Possible	2	Predation by grey seals[3] and killer whales is reported at several locations. Anecdotal reports from Shetland suggest that predation rates may be high in some locations. Two PhD projects are currently investigating predation on harbour seals by grey seals and killer whales.	
Toxins from harmful algae	Possible	2	Domoic acid, saxitoxins and okadaic acid continue to be detected in harbour seals[4] and their prey.	See BP 20/06
Prey quality and availability	Possible	2	It is not possible to rule out changes in prey quantity or quality as factors in the harbour seal decline, although recent analysis of body condition and nutritional health in live captured animals shows no evidence[5].	See BP 20/06
Juvenile dispersal	Possible	2	Genetic studies do not indicate large scale dispersal but may have little power to detect recent changes in recruitment patterns.	
Climate change: indirect effects	Possible	2	Changes in prey distribution and/or availability or increases in harmful algal blooms or increased disease prevalence as a consequence of climate change are likely to impact harbour seal populations in future.	See Q23
Climate change: direct effects	Unlikely	1	Observed and potential changes in physical environment in UK waters are unlikely to exceed harbour seals' adaptive capabilities.	See Q23
Fisheries bycatch	Unlikely	1	Data from bycatch observer programmes and absence of major gillnet fisheries in regions of decline suggest that bycatch is unlikely to be a significant factor in the declines.	See Q14

[3] 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.

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

[5] Kershaw, J., Cummings, C., Bukowski, L., Moss, S.E.W., Arso Civil., M & A.J. Hall (in press) Health and nutritional markers in harbour seals from Scottish populations with differing trajectories. Report to Scottish Government under Marine Mammal Scientific Support Programme 2015-2020. Scottish Marine and Freshwater Series

Factor	Importance status	Confidence level	Evidence	Additional information
Persistent Organic Pollutants	Unlikely	1	Levels of persistent organic pollutants (PCBs, DDTs and PBDEs) are low in the areas of decline and highest in regions where populations are increasing[6].	
Loss of habitat	Unlikely	1	Data from aerial surveys and telemetry studies show no evidence that foraging, moulting or breeding sites have been lost.	
Disturbance	Unlikely	1	Possible local re-distribution effects. Most sites are remote and rarely disturbed. Occasional disturbance does have severe effects. Population trends at sites with high levels of tourism/military aircraft activity and offshore renewable energy developments show no signs of negative impacts at the population level.	See Q25
Emigration	Unlikely	1	Telemetry data do not indicate large scale, permanent emigration of seals away from areas of decline[7], although temporary relocation between regions may be frequent. A recent study suggests a decline in migration from the Moray Firth, North Coast, and/or Orkney local population to Shetland and East Scotland SMUs since the start of the regional declines[8].	
Infectious disease and parasites	Unlikely	1	No evidence of large-scale mortality events from strandings. Live captures show no evidence of disease in areas of decline. However, other esoteric or secondary disease agents cannot be ruled out. Higher mortality rates among rescued juvenile harbour seals in recent years in the SEE-SMU. No information from wild seals and no such reports from declining SMUs in Scotland.	
Illegal killing	Unlikely	1	No evidence of illegal killing at levels that could account for the declines. It can be ruled out in some SMUs e.g. East Scotland but cannot be ruled out as a contributory factor in other SMUs.	
Legal control	No	1	Introduction of the Marine (Scotland) Act 2010 and the licensing system is ensuring the declining populations are protected from directed takes.	
Entanglement in marine debris	No	1	Data from stranded seals indicate that entanglement in marine debris is not a major cause of mortality and not a potential driver of population declines in UK harbour seals.	See Q24
Macroplastics and microplastics	No	2	Data from stranded seals and faecal samples indicate that ingestion of macro- and microplastics is not a major issue for UK seals at the population level.	See Q24

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

[7] Sharples, R.J., Moss, S.E., Patterson, T.A. & Hammond, P.S. 2012. Spatial Variation in Foraging Behaviour of a Marine Top Predator (*Phoca vitulina*) Determined by a Large-Scale Satellite Tagging Program. *PLoS ONE*, 7

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

Seal Legislation

9. Given recent government amendments to the Conservation of Seals Act 1970 and the Wildlife (Northern Ireland) Order 1985, can SCOS review and advise as to whether there is any significant scientific requirement or advantage in making any further legislative amendments for seals in SOS waters? For example, does SCOS believe that the Scottish legislation and nationally important haul out sites better protects seals? **Does SCOS believe that the Scottish system of designated sites helps reduce disturbance?**	Defra Q7 Defra Q11

SCOS does not consider that currently there is a significant scientific requirement for additional changes to the Conservation of Seals Act.

In previous years, SCOS has identified a need for reporting of the numbers of seals shot to defend fisheries, and therefore not requiring a licence in England and Wales. As the amendments to seal legislation have removed the permission to shoot seals for protection of fisheries throughout the UK there should now be no requirement for such reports.
At present there is no monitoring of the effectiveness of the designations of Scottish haulout sites in reducing disturbance. Some Monitoring would be desirable to enable such an assessment to be made in the future.

SCOS highlighted the inconsistency in regulations in different parts of the UK regarding seal protection and specifically protection of seals at haulout sites from deliberate harassment

SCOS 2019 considered that the methods used in Scotland to identify sites for national designation could be applied in the same way to sites in England and Wales. As discussed in answer 26 below there has been no monitoring of the success, or otherwise of the Scottish seal haul out designation legislation in reducing deliberate harassment at haul outs and only patchy information on levels of disturbance, with no assessment of the effects of the legislation. In addition, as also discussed in answer 25, there is no definitive evidence that disturbance is currently causing a problem at any seal haul outs within SOS waters. However, it is clear that the legal protection afforded by the seal haul out designation does provide a framework for activities causing disturbance at designated haul outs to be reported and subsequently managed. The public awareness of this protection may be contributing significantly to seal protection in some locations.

The removal of the netsman's defence from the legislation has removed one of the control options available to fishers who experience problems with seal depredation. This, along with the perceptions of fishers reported in answer 17 (MMO, 2020a) that conflicts are increasing due to increasing seal populations, may result in a greater risk of deliberate disturbance of seal haul outs in hotspots of high seal depredation. However, this is purely speculative at this point and evidence would be required before a science-based recommendation for the need for greater protection could be made.

SCOS highlighted the inconsistency in regulations in different parts of the UK regarding seal protection and specifically protection of haulout sites from deliberate harassment. Under the Marine (Scotland) Act 2010 it is an offence to deliberately harass seals at designated haulout sites, under The Wildlife (Northern Ireland) Order 1985 seals are protected at all times from deliberate disturbance but in England and Wales there are no specific protections from disturbance at haulout sites.

SCOS considers that any putative changes to legislation in response to perceived increases in disturbance, will need to be based on a clear scientific understanding of the issues. This should be based on information on the scale and extent of the disturbance issue, the behavioural, welfare and fitness consequences for individual seals and the population scale effects. These aspects are discussed further in answer 26.

Seal Licensing and PBRs

10. Can SCOS provide updated Potential Biological Removals (PBRs) figures for 2021?	MS Q6

PBR estimates for both harbour and grey seals for each seal management unit (SMU) in Scotland, together with a description of the calculations and the rationale for selection of SMU specific Recovery Factors (F_R) are presented in SCOS-BP 20/07. PBR values for the grey and harbour seal "populations" that haul out in each of the seven SMUs in Scotland are presented here (Tables 8 & 9), based on suggested values for the recovery factor and the latest confirmed counts in each management area.

Compared to last year:

- **Recovery factors have been held constant for both species in all SMUs.**
- **The latest harbour seal survey counts for the North coast and Orkney, and for the Moray Firth SMUs were similar to previous counts and there has been no change in the PBR estimates for those management units.**
- **The grey seal counts for the North coast and Orkney, and the Shetland SMUs were approximately 12% and 35% respectively lower than previous estimates. The Moray Firth count was 115% higher than the previous count. These changes result in pro-rata changes in PBRs for grey seals in those SMUs.**

Table 8. Potential Biological Removal (PBR) values for harbour seals in Scotland by SMU for 2021. The most recent population data, estimates of N_{min} and the recommended F_R values are shown.

Seal Management Unit	2016-2019 count	N_{min}	selected FR	PBR
1 Southwest Scotland	1709	1709	0.7	**71**
2 West Scotland	15600	15600	1.0	**936**
3 Western Isles	3532	3532	0.5	**105**
4 North Coast & Orkney	1405	1405	0.1	**8**
5 Shetland	3180	3180	0.1	**19**
6 Moray Firth	1077	1077	0.1	**6**
7 East Scotland	343	343	0.1	**2**
SCOTLAND TOTAL	26846	26846		**1147**

Table 9. Potential Biological Removal (PBR) values for grey seals in Scotland by SMU for 2021. The most recent population data, estimates of N_{min} and the recommended F_R values are shown.

Seal Management Unit	2016-2019 count	Nmin	selected FR	selected PBR
1 Southwest Scotland	517	1995	1.0	**119**
2 West Scotland	4174	16111	1.0	**966**
3 Western Isles	5773	22283	1.0	**1336**
4 North Coast & Orkney	8599	33192	1.0	**1991**
5 Shetland	1009	3894	1.0	**233**
6 Moray Firth	1657	6396	1.0	**383**
7 East Scotland	3683	14216	1.0	**852**
SCOTLAND TOTAL	**25412**	**98087**		**5880**

11. PBR and bycatch[9]: The PBR for in the population of grey seals SW England, Wales and Ireland is 283, using a Recovery Factor of 0.5. Bycatch in that same area far exceeds this. **a: Does the spatial scale of this area adequately represent the appropriate scale for the population (see question 1)?** **b. What are the latest bycatch estimates for grey seals in Ireland, SW England and Wales, and the four putative MU areas based on combinations of ICES areas (see Q 12 for description of putative SMUs)?** **c: What would SCOS recommend the FR should be for the particular use we are considering here (ie HRA) and why?** **d: Despite this PBR and bycatch, populations in the region (pups) are increasing suggesting the PBR is not correct for several reasons. What is SCOS' explanation for this disparity?** **e: What alternative approaches do SCOS suggest might be plausible for determining how many removals (mortalities) in the region is too many?**	NRW Q5

[9] This is a condensed version of the original text for this question. The full text together with a rationale for the question can be found in Annex II.

a: Does the spatial scale of this area adequately represent the appropriate scale for the population?

The continued growth of the south west UK grey seal population despite the fact that fisheries bycatch likely exceeds the combined PBRs for the Southwest England and Wales SMUs and Ireland clearly suggests that it would be inappropriate to assess the bycatch against the PBR for any one of these SMUs.

This is not a problem specific to PBR, it would be a problem for any population dynamics-based management method. It is primarily an issue of defining appropriate population units for effective population-based management. With the existing SMU structure, it is a question of how to combine SMU populations in an appropriate way, and how to allocate the resulting permissible takes to different SMUs or different activities across combined SMUs.

Pooling SMUs across regulatory boundaries would require some assessment of the proportion of animals in the bycatch that originated in and were destined to return to each SMU to 'apportion' the overall PBR of the pooled SMU to the different regulatory authorities involved. Developing an appropriate solution will require a thorough re-assessment of the management process involving the SNCBs and seal population biologists.

For management decisions that occur within a single SMU the relevant PBR would be derived using the N_{min} value for the population in that SMU. The reference to a combined population in SCOS 2018 (*Ireland, SW England and Wales*) was not a recommendation that they should be pooled for making management decisions, but was used simply to indicate the scale and importance of the bycatch relative to the grey seal populations in the southwest of the British Isles.

On face value, a bycatch occurring within a SMU should be assessed against the PBR for that SMU. For a widespread or dispersed anthropogenic take such as bycatch there may be some ambiguity about what population unit is relevant. However, it is important that decisions to coalesce SMUs to generate larger PBRs should be based on an a-priori assessment of the relevant population. If an issue clearly affects populations in more than one SMU it could be argued that the relevant N_{min} should be based on the combined population in those SMUs, but, if the take occurs in one SMU but affects temporary migrants from another SMU, the calculation become more difficult.

The PBR calculates the number of animals that can be taken from a population while still allowing it to tend towards its optimum sustainable population (OSP). Implicit in this calculation is that the population unit being considered will respond in a density dependent manner i.e. its growth rate will depend on the size of the population relative to the carrying capacity. There is no way to account for immigration or emigration in the PBR calculation, therefore the population unit is assumed to be closed. This assumption will rarely be the case for seal populations in SMUs within the UK. The degree to which a population can be considered closed is one of the factors taken into account when deciding on the F_R applied when calculating the PBR for each SMU in Scotland.

A single set of SMUs have been defined for both species. The delineations of these SMUs were based on multiple factors: (1) practicalities of carrying out synoptic surveys of entire SMUs, (2) respecting national boundaries due to differences in management plans and (3) minimisation of movements between different SMUs both with the foraging season, and between the foraging and breeding season. Essentially to effectively manage a population, information on abundance and trends therein, is required. For harbour seals, SMRU aim to cover the entire Scottish coast every five years, the current management units maximise the ability for entire SMUs to be surveyed in a single year, allowing estimation of trends (Thompson *et al*., 2019).

Defining population units for both species is problematic but such units are likely to be on a greater spatial scale than the scale at which most management decisions are made. For harbour seals, it seems likely that the UK population can be split into two metapopulations (Scotland and Northern Ireland, and east England), with geneflow within these units. These metapopulations are not contained within the UK, with the east England population being part of the continental European population. The wide-ranging movements of grey seals pups (Carter *et al.,*2017) and adults (Carter *et al.,* 2020) suggests that the UK is part of a bigger European metapopulation. For harbour seals which are widely distributed along the coastline and throughout the Northern and Western Isles of Scotland there are few clear breaks in the distribution around the coast. However, on the assumption that long range movements between breeding areas were uncommon, it was assumed that if the management units are large enough, the effect of movement across the boundaries between SMUs would be relatively small.

For grey seals in the UK, the calculations are complicated by the mixing of different SMU populations outside the breeding season. The long-range dispersal of grey seals away from their breeding sites means that the breeding population in any one area may be subject to anthropogenic pressures in several SMUs. Conversely, outside the breeding season, the population of grey seals within a SMU will likely comprise unknown proportions of seals from breeding populations in several different SMUs. The situation is further complicated by the fact that some SMUs, e.g. the Moray Firth, have substantial numbers of grey seals outside the breeding season but produce only small numbers of pups.

For managing Scottish grey seal populations, it was decided that since they spend the majority of their time away from breeding colonies and the majority of anthropogenic impacts will occur during these foraging periods, the most appropriate option was to calculate PBRs for the local summer populations within each SMU (based on August surveys). It was recognized that this definition does not meet the criterion of a closed population, but it was chosen as the best option to manage anthropogenic impacts in different SMUs.

For the Welsh and SW England SMUs there are no regionwide summer survey data with which to assess the summer population. PBR calculations have therefore relied on N_{min} estimates derived from application of a simple multiplier to the pup production estimates.

There will often be a mismatch between the scale of population unit appropriate for estimating PBRs and the spatial distribution of anthropogenic activities. For example, the concentration of takes by localised activities such as construction and operation of marine renewable developments will likely only impact seals in a small part of a SMU.

There is no formal structure for dealing with such situations, but a simple and pragmatic solution may be to allocate the PBR in relation to the local population at whatever scale is required for each management decision. For example, if an activity is localised in an area that holds 10% of the seal population in a SMU, then the potential take could be considered with respect to 10% of the PBR for the entire management unit. However, justifying such an allocation would need to take account of the turnover of the local population and temporal scale of movements to assess the proportion of the SMU population that should be apportioned to the impact area. Such a local allocation scheme would require detailed information on the distribution and movements of seals within the SMU, requiring information from recent SMU wide population surveys or some form of predicted seal density map derived from a habitat preference model.

The problem with the bycatch of grey seals in SW British Isles is complex. In this case the problem is that the take appears to exceed the PBR, even when calculated for a combined population for three UK SMUs, and Ireland, yet the breeding population in Wales continues to increase. Potential reasons for the continued growth are addressed below.

The suggestion by NRW that a larger group of SMUs should be pooled is problematic. Simply pooling SMUs around the west coast of the UK and Ireland, to account for a by-catch that is concentrated in the south-west may erroneously inflate the population assumed to be at-risk. It may be possible to apply the method suggested above and attempt to quantify the proportion of the population in each of the pooled SMU populations that would be in the at-risk sub-population. However there is no independent estimate of the proportion of the seals in those SMUs that are at risk from the bycatch in the south-west, i.e. although there is evidence of movement between regions along the west coast, there are no reliable estimates of the scale of that movement and more importantly, very little information on the movements of pups from the large, adjacent population in the Hebrides that is the most likely source of immigrants, and hence no information on turnover in the at-risk population.

Pooling the SMUs and 'apportioning' the total pooled PBR appropriately to each SMU would require some assessment of the proportion of animals in the bycatch that originated in and were destined to return to those remote SMUs. Such an assessment should ideally take into account factors such as the age distribution of the take and the apparent mortality rates applying to the source population. E.g. if a population is close to carrying capacity as seems to be true of the West Scotland grey seal population, pup mortality is expected to be large. A take of even 50% of pups, not long after leaving the beach, would have little effect on the population trajectories in the source region. At present we have insufficient information on which to base such judgements, but a project to track a sample of pups from the Hebrides is planned for 2021 should provide the required information.

b. what are the latest bycatch estimates for grey seals in Ireland, SW England and Wales, and the four putative MU areas based on combinations of ICES areas?

The latest bycatch statistics for seals killed by UK registered vessels by ICES Area for 2018 are presented in Northridge *et al*. (2019). There data are presented for grey and harbour seals combined. However, a large majority of cases were grey seals, and in the southwest fisheries the bycatch was almost exclusively grey seals. The bycatch estimates can be summed to produce the following estimates:

1. **ICES Areas 7a, 7g and 7f - Celtic Approaches and Irish Sea - 129**
2. **ICES Areas 7a, 7g, 7f, 7j, 7h, and 7e – Celtic and Irish Seas - 302**
3. **ICES Areas 7a, 7g, 7f, 7j, 7h, 7e, and 7b – Celtic and Irish Seas and West Ireland - 302**
4. **ICES Areas 7a, 7g, 7f, 7j, 7h, 7e, 7b and 6b – Western British Isles or OSPAR Region III – 311.**

Although it is relatively easy to combine the published estimates of UK fishing vessel bycatch for the putative management areas these numbers do not represent the total seal bycatches for any of these areas/combinations of areas. A substantial number of vessels registered in other nations, primarily Irish and French vessels, fish in the same waters using similar gear with a significant seal bycatch. Luck *et al*. (2020) estimated total bycatches of between 202 and 349 seals per year within the Irish EEZ by all vessels. Unfortunately, these cannot be simply added to the UK vessel bycatches as the Irish EEZ figures will include some of the UK registered vessel bycatch. Although bycatch was not broken down by country of registration, the fishing effort by French vessels (43%) was similar to the combined effort by Irish (21%) and UK (23%) registered vessels in the Irish EEZ. In addition, some French and Irish vessels fish in UK waters and will also likely take seals as bycatch but are not included in either Northridge or Luck's estimates.

The UK vessel estimates therefore represent an unknown proportion of the overall bycatch off the southwest British Isles. Producing robust estimates of total bycatch in each management region would be possible but will require a specifically targeted and resourced research effort.

c: What would SCOS recommend the F_R should be for the particular use we are considering here (i.e. HRA) and why?

The choice of recovery factor (F_R) is a management decision. PBR has a degree of precaution built in, but the F_R was incorporated to allow managers to apply a further, variable degree of caution when applying the method.

The choice of recovery factor is a management decision, it is designed to allow managers to apply a variable degree of extra caution when applying the PBR method. PBRs for all Scottish grey seal SMU populations are calculated with a recovery factor of 1.0 (SCOS-BP 20/07). This is because there has been sustained growth in the numbers of pups born in all breeding areas in Scotland and along the North Sea coasts of England over the last 30 years. All Scottish and adjacent English east coast breeding populations are either increasing or are apparently stable at the maximum levels ever recorded and therefore assumed to be at or close to their carrying capacities (Lonergan *et al*., 2011b; Thomas *et al*., 2019; Russell *et al*., 2019).

Pup production time series are not available for a significant proportion of Welsh grey seal breeding sites (SCOS-BP 20/04). The larger colonies are monitored regularly, but even some of these, e.g. Ramsey Island, are estimated by scaling up counts of pups on indicator sites, which, in the case of Ramsey Island, are thought to represent approximately half of the pup production. There are therefore no realistic confidence intervals for the Welsh grey seal pup production, but they must be assumed to be wide due to the lack of data from large sections of the population. Under such circumstances, the choice of a precautionary F_R may be sensible.

Conversely, where sites are monitored regularly, e.g. Ramsey, Skomer, Marlowes Peninsula and Bardsey Island, the pup production appears to have increased. This suggests that whatever takes are occurring, they are not preventing the population from growing. Indeed, if the assumptions of the method are correct, removing the PBR should not prevent a population from growing (see below).

It is not clear why a different F_R would be applied when considering SACs as the PBR provides an estimate of the number of removals that can be considered safe in terms of ensuring that the whole population tends towards the optimum sustainable population (OSP) level. In situations where there is more uncertainty about the nature of impacts or the status of populations, a lower F_R will provide a more precautionary PBR estimate.

d: Despite this PBR and bycatch, populations in the region (pups) are increasing suggesting the PBR is not correct for several reasons. What is SCOS' explanation for this disparity?

A population below the optimum sustainable population (OSP) level should increase if the PBR is removed. However, if the population continues to increase while the real bycatch is much larger than the PBR , the PBR estimate may be too low. This could result from underestimating

population size, applying an overly conservative F_R, immigration from other populations or some combination of these and other factors.

As stated above, the PBR is an estimate of the number of animals that can be removed from a population while still allowing it to approach its OSP level. Thus, a population significantly below the OSP would be expected to continue to increase even if the PBR were removed each year. If the assumptions of simple density dependent population control hold, a depleted population should continue to grow if a PBR calculated with F_R=1.0 were removed each year. Given the uncertainty in the population estimates and in the estimates of bycatch we cannot be certain that the observed growth is unfeasible.

If the real bycatch does exceed the PBR but the population continues to increase, the PBR estimate may be too low. This could result from underestimation of the population size, an overly conservative F_R, or immigration from other populations or some combination of these and other factors.

e: What alternative approaches do SCOS suggest might be plausible for determining how many removals (mortalities) in the region is too many?

A range of alternative population modelling approaches for assessing anthropogenic impacts are available. Several such models were reviewed by Sparling et al. (2017) to provide an accessible summary reference guide to marine mammal population modelling for statutory nature conservation bodies (SNCB) for assessing potential impacts on marine mammal populations. There are essentially two types of approach, PBR which assumes a simple density dependent population dynamics model and has a fixed target population, and more flexible but more complex predictive modelling methods with species specific population dynamics models and population targets determined on the basis of specific management objectives.

These methods originated from the management of populations subject to either deliberate removals e.g. hunting, or accidental removals e.g. bycatch. They use information on the current size and health of populations to set thresholds on the number of individuals that can be removed without having a significant detrimental effect on the population. In addition to the PBR, three other methods have been developed specifically for managing marine mammal populations under exploitation: the International Whaling Commission Revised Management Procedure (IWC RMP) which was developed to set safe limits for sustainable harvesting of whale populations (Cooke 1999, https://iwc.int/rmpbw), the Canadian Precautionary Approach to Marine Mammal Harvests (Stenson *et al.,* 2017) and the ICES seal harvest model (ICES, 2013; Øigård *et al*., 2014; Øigård & Skaug, 2015).

The PBR is widely used because it requires only one population estimate and an estimate of the intrinsic rate of increase for the species/population under consideration. However, the method does not allow for any modification of the underlying population model and has a fixed or assumed management target. The IWC RMP, Canadian Precautionary Approach and the ICES seal harvest model are based on more flexible and therefore potentially more realistic population models, that are parameterised for each species under consideration. Such models allow assessment of the population under a range of exploitation/additional-mortality scenarios and can accommodate a wide range of management targets. Unlike PBR, these methods require specific estimates of population parameters and time series of population estimates.

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

A number of off-the-shelf software packages have been developed to carry out predictive modelling as part of a PVA e.g. VORTEX (Lacy, 2000) and ULM (Unified Life Models; Legendre & Clobert, 1995). VORTEX has been used as a predictive modelling tool in the assessment of the impact of offshore wind farm construction on bottlenose dolphin populations in the Moray Firth and the outer Firth of Tay (De Silva *et al*., 2014) and for cumulative assessments on the east coast of Scotland by Marine Scotland Science. Similar methods were used in the 'Moray Firth Seal Assessment Framework' (MFSAF; Thompson *et al.,* 2012), where an existing stage-based matrix model of the harbour seal population in the Moray Firth was used to simulate the trajectory of impacted and baseline populations.

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

In principle, the impact of "takes" such as bycatch could be incorporated into the population-model currently used to estimate grey seal population size (Thomas & Harwood, SCOS-BP 04/07; Thomas *et al*., 2011). However, this would involve modelling "takes" using the breeding distribution rather than the summer distribution which is currently considered. Other considerations would be the restricted spatial extent of the population model, and how the regions of the population model relate to the SMUs. The southwest UK is not incorporated in the UK population models (SCOS-BP 20/04). In any case, using a population model would be unlikely to generate increased allowable takes for the southwest given the sparsity of data on pup production, and the lack of information on the proportion of bycatch from each breeding population.

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

12. Management Units **As a pragmatic solution to the lack of agreed MU for grey seal (and potentially common seal) in the region, NRW would like SCOS to calculate the pup production and population estimates for grey seal (and common seal) and explore the validity of the science supporting four putative MU spatial scales:** **1. ICES Areas 7a, 7g and 7f - Celtic Approaches and Irish Sea**	NRW Q4

2. **ICES Areas 7a, 7g, 7f, 7j, 7h, and 7e – Celtic and Irish Seas** 3. **ICES Areas 7a, 7g, 7f, 7j, 7h, 7e, and 7b – Celtic and Irish Seas and West Ireland** 4. **ICES Areas 7a, 7g, 7f, 7j, 7h, 7e, 7b and 6b – Western British Isles or OSPAR Region III**	

Justification for existing Seal Management Unit structure is discussed in the previous answer (11 above). Issues around generating seal population and pup production values in the proposed ICES areas are addressed in answer 3 above.

SCOS do not consider that the proposed structure based on ICES fisheries areas has more justification than the more pragmatic selections based to some extent on monitoring capabilities and management jurisdictions

Population data in the form of pup production estimates for UK grey seals and moult counts for UK harbour seals are presented in tables 2 and 4 respectively. Most recent data for Republic of Ireland grey seal pup production and harbour seal moult counts are presented in tables 3 and 4 respectively. These data can be combined to produce estimates for each of the putative management units.

The Republic of Ireland data are currently presented as a single national estimate. The current management units are shown in Figure 4 and the justification for their selections is presented in answer 11a above along with a discussion of the issues associated with coalescing SMUs to provide larger PBRs for widespread issues. The main problem is the potential for the management to be less sensitive to impacts at local scales by assessing their population effects on larger population units.

The boundaries of the current SMUs were set for a number of pragmatic reasons described above. There would appear to be no more justification for selecting the boundaries of ICES statistical areas and sub-units which were defined for fish stocks than the more pragmatic selections based to some extent on monitoring capabilities and management jurisdictions.

There is no reason why estimates from adjacent SMUs cannot be combined to address issues such as bycatch that clearly involve or have a potential impact on seals from multiple SMUs. This would allow population management to be based on the existing SMUs while giving the required geographical coverage indicated in the question.

A problem with such combination is the inclusion of data from adjacent countries, in this case the Republic of Ireland and France. Both Irish and French seal distribution and abundance data will be included in the pending OSPAR assessment due in late 2021. However, the available published data for Irish grey seals are more than 10 years old. A time series including more recent grey seal pup production estimates is expected to be published in 2021. Harbour seal population estimates are presented as a single figure for the Republic of Ireland. However, the data are collected using the same survey methods as in the Scottish helicopter surveys and could presumably be made available in smaller units. Use of data from other jurisdictions will require formal data sharing arrangements.

As discussed in answer 6 above, on the basis of genetic differences there appears to be a degree of reproductive isolation between grey seals that breed in the south-west (Devon, Cornwall and Wales) and those breeding around Scotland (Walton & Stanley, 1997) and within Scotland, there are significant differences between grey seals breeding on the Isle of May and on North Rona (Allen *et al., 19*95). There is therefore some indication of sub-structure within the UK grey seal population, but it is not strong. On the basis of telemetry studies (Russell *et al.,* 2013) there is significant mixing of grey seals from different SMUs outside the breeding season, but the majority of seals breeding in a SMU will remain in it throughout the year. There is therefore little evidence of clearly defined population units. In these circumstances the decisions on management units must come down to a balance of precaution and practicality and becomes effectively a management decision rather than a scientific one.

<u>SAC Condition indicators</u>

13. SAC condition indicators. **In addition to measures of pup production, quality of habitat and distribution of pupping sites for SACs where grey seals are qualifying features, what other indicators might reliably provide a measure of condition of SAC features and indicate how well the population is doing? (e.g. population structure/dynamic indicators, such as degree of site fidelity, age structure, fecundity (crude birth rates), pup survival, mortality etc). Can any of these population dynamic factors be reliably measured and are these useful at a smaller (e.g. site-based, regional) scale?**	NRW Q6

The usefulness of different population parameters as site condition indicators depend on the management objectives for the SAC. For grey seals, pup production time series provide a consistent index of population size, and trends in pup production will be robust indicators of population trends. While pup production can provide an indication of the health and status of seals breeding within an SAC, such local measures do not necessarily provide a reliable indicator of the status of the wider UK population.

Changes in relative magnitude of pup production at different locations within an SAC may not provide useful information on changes in site condition.

Site fidelity, age structure, pup survival and adult survival are extremely difficult to measure and require substantial, long-term labour-intensive studies to generate useful results. Such methods may be applicable at certain sites but rolling them out as monitoring for all SACs is likely to be prohibitively expensive and/or impractical.

The usefulness of different population parameters as site condition indicators depend on the management objectives for the SAC. Presumably, in this case the condition that is to be assessed is the conservation status of the local population within the SAC.

Pup production can provide an index of both population size and productivity, and a time series of pup production estimates can provide an indication of the recent population trend, which will depend on local and larger-scale population dynamics, and migration in/out of the area.
The population dynamics model for Scottish and English east coast grey seals suggests that density dependent control of the grey seal population is acting through changes in pup survival, primarily due to post weaning mortality at sea. This also suggests that the trajectory of the total population will closely track the trajectory of pup production. Therefore, pup production estimates will provide an effective index of population size and status.

While pup production can provide an indication of the health and status of seals breeding within a particular SAC this does not necessarily provide a reliable indicator of the status of the wider UK population or even the status of other breeding sites in the vicinity of the SAC. For example, throughout the 1980s and 1990s the numbers of seals pupping on most of the older long-established breeding colonies in the Outer Hebrides declined continuously. However, this was more than compensated for by the rapid increase in pup production in the Monach Isles, such that the overall pup production of the Outer Hebrides grew rapidly (Russell *et al*., 2019). In this case the rapid declines in older colonies may have indicated a preference by recruiting females for the open sandy habitat in the Monach Islands, rather than a developing problem at the older colonies.

The number and distribution of breeding sites within an SAC and the relative abundance of pups on those sites have been proposed as potential indicators of site condition. For sites such as those on open sand beaches the colony is likely to expand and contract with population size. However, on more constrained sites such as small coves and cliff beaches large changes in density may occur without any change in extent of breeding sites.

If grey seals in a region are regarded as comprising a metapopulation, the development, growth and occasional extinction of local sub-population units could be regarded as an intrinsic population process. The importance of local population changes will be scale dependent; local fluctuations may be stochastic events whereas temporal change at a large scale is more likely to be related to overall resource levels etc. Within a metapopulation, undocumented or time-varying movements of animals between sites will make it difficult to interpret observed changes in any monitored population metrics.

Whether estimates of the degree of site fidelity, age structure, fecundity, pup survival, mortality etc. can be used as condition indicators depends on feasibility (i.e. whether the needed data are available or can be readily collected) and on the management targets for the monitoring programme.

The management implications of site fidelity are not clear. There will be individual and age-related differences in site fidelity, but a targeted research programme will be required to estimate site fidelity for samples of seals at any one site, requiring intensive photo-ID studies and/or telemetry. Assessing site fidelity at all SAC sites would seem prohibitively expensive in terms of resources. Even if it could be routinely monitored, any observed changes in site fidelity may be difficult to interpret without concurrent information on potential explanatory covariates, such as those related to habitat quality.

Age structure can provide indications of past changes in recruitment and therefore in pre-recruitment survival and estimates of adult survival, but the operative word is "past". This is not a real time indicator of changes in site/population condition. Age structure can only be derived from lethal sampling of a cross section of the population, long-term mark-resighting studies or through population modelling based on long-term pup production time series and other information. Lethal sampling is not acceptable (under UK legislation) and long-term mark resighting studies at all SACs will be practically extremely difficult and again seems unlikely to be a cost-effective monitoring method.

It may be possible to measure some simple proxy for age structure such as the relative proportions of different size classes to estimate population descriptors such as changes in relative proportion of juveniles to adults. Booth *et al.* (2020) suggested that changes in the proportion of immature animals in a population could be a useful 'early warning' indicator of the impact of disturbance. However, this would suffer from similar issues of scale and expense if it were to be rolled out.

Fecundity and both pup and 1+ survival rates are extremely difficult to measure directly. Birth rates of seals seen at colonies provide limited information on population scale fecundity, because non-breeding mature females might not be seen at the breeding colony. Intense, long term mark resighting work at the Isle of May and North Rona and branding work at Sable Island have produced useful information on fecundity and both pup and adult survival, facilitating comparison of rates between colonies. However, intensive research effort conducted over many years was required at each site to produce meaningful results. It is difficult to see how such methods can be applied at all SACs to provide cost effective indices of condition.

Estimates of the condition of mothers (in this case meaning fatness) on breeding colonies would be some indication of (a) previous foraging conditions and (b) likely pupping success. Fatness (condition) estimates of seals on non-breeding haulouts would also be instructive. In the special case where individuals are identifiable and site faithful, a longitudinal record of condition can be derived (Hanson *et al*., 2019). Again, this would require a labour-intensive research programme at a select number of sites and will be unlikely to be cost effective as a site condition index for multiple SACs.

While the cost and practicability of these methods means that they are unlikely to provide consistent indicators across all SACs, in some cases, where staff resources and accessibility of seals allows, mark resighting studies in the form of structured photo-ID programmes can provide useful indices of survival and potentially fecundity rates for seals at specific sites, particularly when combined with pup production estimates collected at the same sites.

Although, counts of seals on haul out sites during the summer could provide an indication of sustainable foraging opportunities in range of the SAC. If combined with photo-ID studies this could provide estimates of the numbers using the sites, turn-over rates and trends therein, and could potentially be cross referenced with bycatch studies.

In some circumstances recording frequency of carcass strandings and cause of death data may provide crude indicators of local population health. The variability in probability of carcasses stranding and lack of any regular monitoring program means that this will not provide useable estimates of mortality rates, but may provide early indications of significant mortality events such as PDV Outbreaks or temporal trends in local mortality rates.

Seal Bycatch

14. What is the latest information on levels of seal bycatch across the UK? Are there particular seasonal and / or geographical hot spots of high seal bycatch? Are there any areas where it has not been possible to collect seal population/bycatch data? **In the 2019 advice, SCOS provided a bycatch estimate for grey seals in UK waters, although the estimates were largely based on observed rates from sampling focused in a particular region. Can SCOS advise whether there are potential fisheries or areas where bycatch could be a concern, and which would benefit from extra sampling in order to increase confidence in the bycatch estimates?**	Defra Q4a MS Q7

The most recent estimated bycatch of seals in UK fisheries was in 2018 and reported in SCOS 2019. The total estimate was 474 animals (95% CI 354-911). This estimate is based on bycatch in gill net/tangle net fisheries; rare and sporadic captures in trawl fisheries are discussed below. The estimated bycatch was lower than in 2017 because of a continuing reduction in fishing effort between 2016 and 2018. Approximately 85% of the bycatch estimate occurs in the south-west, in ICES area VII, where the UK gillnet fishery is concentrated. The remainder occurs in area IV which covers the North Sea and waters around Shetland and Orkney with less than 1% occurring in area VI around the Hebrides and Northwest Scotland.

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

Seal bycatch estimates

Seal bycatch estimates for the UK are made for both species of seal (grey and common/harbour) combined (Northridge *et al*., 2019). Most seals that have been examined were young grey seals which can be hard to differentiate from harbour seals. All seals taken in gillnets were thought to be grey seals and were taken in the southwest where harbour seals are rare. The numbers of harbour seals recorded are too low to generate a useful bycatch estimate, so for expedience a single combined seal bycatch total is calculated. Although it is reasonable to assume that the majority of these are grey seals, in the North Sea at least, some proportion will likely be harbour seals. SCOS recommend that effort should be directed towards identifying the species and if possible the sex and age structure of the bycaught seals. This could be achieved by obtaining photographs of the animals.

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

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

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

Information on UK seal populations is available in terms of distribution of haulout sites and numbers of seals counted at those sites during surveys conducted in August, for all areas except for southwest England and Wales. The data are collected on a roughly five yearly cycle except for the East coast of England and Scotland that are surveyed annually. In Wales and Southwest England data on grey seals are available during the breeding season and from sporadic and scattered counts during the summer (SCOS-BP 20/04).

Recent analysis of data from the Irish EEZ (Luck *et al.,* 2020) shows that bycatch rates are related to proximity to areas of high seal density, around haulout sites and in inshore waters in particular. That analysis suggests that bycatch estimates can be significantly biased by the distribution of sampling effort. Increased marine mammal bycatch monitoring on French, Irish and other EU registered vessels fishing in this region would be helpful. UK sampling has covered all vessel categories (inshore and offshore) in this region, though sampling from Welsh ports and in the Bristol Channel has been limited and could be increased. The potentially large takes in these fisheries mean that the bycatch rates presented above may significantly under-estimate the scale of the problem.

The published data are not presented at sufficiently high resolution to ascertain whether there are any particular local hotspots of by-catch within particular ICES areas, but we are not aware of any such persistent hotspots. Table 9 shows the estimates by ICES Division and general area. Approximately 82% of the bycatch (390 seals) was estimated to have occurred in ICES area VII, around the south and south-west of the UK and Ireland. The majority of this occurred in the Western Channel and Celtic Sea, (300 seals per year), largely due to the overlap of high levels of fishing effort and relatively high seal densities. Bycatch rates in the Eastern Channel are estimated at around 88 seals per year.

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

In addition to the 474 seals caught in gill nets, six grey seals were reported caught in sandeel trawls in 2018, the first such records from a trawl fishery for some years. Although this appears to be a high rate, seal bycatch records in trawl fisheries are clumped, often involving several individuals in one location, but are overall very rarely recorded events in both the targeted marine mammal bycatch programme and Cefas/AFBINI discard monitoring programmes. The overall observed mean bycatch rate is therefore very small and will have extremely wide confidence intervals, so without a clearer understanding of the spatial and other factors that lead to such bycatch events, these numbers have not been included in the 2018 seal bycatch estimates.

Although the total bycatch estimate of 474 is not large compared to the entire UK grey seal population of over 150,000 animals, the local populations around the Celtic Sea, where most bycatch is known to occur are much lower. Total combined pup production in SW England, Wales and Ireland was approximately 4100 in 2016. With the same assumptions as used to derive a PBR for the Welsh grey seal population (N_{min} = 2.3*pup production; FR = 0.5 (SCOS 2016 answer to Q9)) this pup production produces a PBR of 283 grey seals. Using the less conservative recovery factor (FR = 1.0) applied to Scottish grey seal populations would increase this PBR to 566. The current estimated bycatch for UK registered vessels in ICES areas 7 a, e, f, g & j was 300 (Table 9), approximately 6% greater than the conservative PBR.

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

The UK vessel estimates therefore represent an unknown proportion of the overall bycatch off the southwest British Isles. Producing robust estimates of total bycatch in each management region would be possible but will require a specifically targeted and resourced research effort.
It therefore seems probable that the actual bycatch is significantly higher than the non-conservative PBR for the combined SW England, Wales and Ireland population.

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

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

Despite the fact that the recorded bycatch levels are high relative to local population estimates, the grey seal pup production in the region continues to increase. For example, regularly monitored colonies in Pembrokeshire are increasing by around 6% p.a. (Bull *et al.,* 2017 a,b, Lock *et al.,* 2017, Morgan *et al.,* 2018). A large proportion of the bycaught seals were assessed to be first- or second-year animals and first-year mortality is thought to be high in grey seals (SCOS-BP 20/02). If the bycatch mortality pre-dates this enhanced pup mortality it may have a relatively small effect on the dynamics of the populations. Notwithstanding such effects, the bycatch seems unlikely to be sustainable by local populations alone. That they continue to increase suggests that the removals may include or are being compensated for by immigrants. The most likely source of immigrants would be the large breeding colonies in the Hebrides where the population has been relatively stable and where post weaning juvenile survival rates are estimated to be low (SCOS-BP 01/20).

The scale of bycatch relative to local population size in the Celtic Sea suggests that significant immigration is likely occurring. We do not know the immigration rate of grey seals into the Celtic Sea. Ongoing telemetry studies with grey seals at Islay, the Monach Isles and the Welsh Dee Estuary do not indicate large scale movements between the south-west and north-west populations in the UK and Ireland. However, these studies have concentrated on adult seals. The bycatch is almost exclusively young grey seals for which we have no useful telemetry information with which to examine movements from the potential source populations in the Hebrides. The lack of information on the source of seals caught in the Celtic Sea needs to be investigated but the status of local grey seal populations does not indicate an immediate conservation concern.

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

The bycatch of marine mammals and birds in trawls and some other gears in Scottish waters has not been well documented. It was reported during the 1980s for example that porpoise bycatch in demersal trawls off Shetland was not uncommon, and there are anecdotal records to suggest that seals too may be caught in demersal trawls in some areas. Furthermore, gannets among other seabirds are recorded caught in trawl fisheries, while warp strike which is known to affect long winged birds in the southern hemisphere has not been considered in the UK trawl fisheries at all.

Scottish Government have commissioned a desk study, as part of the MMSS project, initially to consider the scale of effort among those sectors that have so far not been sampled, and an assessment of what sampling levels might be sensible if these sectors were to be sampled for impacts on protected species.

The study will look at fishing effort by gear type, the distribution of effort by region and season, and will synthesise known accounts of protected species bycatch in each sector. A risk-based approach will be used to determine which species and gear combinations might be most in need of sampling and produce initial assessments of the scale of sampling needed to provide useful bycatch assessments. This work is due to report in 2021 and results will be presented to SCOS 2021.

15. Can SCOS also provide advice on how to collect additional information on seal bycatch for UK? For example, could SCOS recommend the value of increased reporting of seal strandings and post-mortems through CSIP? Advise on the value of Remote Electronic Monitoring (REM) on fishing vessels, the potential value of voluntary bycatch data recording by fishers (Noting that this is a Defra decision to make), and provide an update on the HBDSEG proposal (UK Seal monitoring) mentioned in 2019?	Defra Q4b

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

REM can produce detailed, useful information on bycatch, but the post processing effort to identify and quantify bycatch events will be substantial.

Recovery of stranded seal carcasses will not provide reliable estimates of bycatch rates, but will provide useful information on species, sex and age classes as well as other biological data.

Recent analysis of data from the Irish EEZ (Luck *et al*., 2020) shows that bycatch rates are related to proximity to areas of high seal density, around haulout sites and in inshore waters in particular. That analysis suggests that bycatch estimates can be significantly biased by the distribution of sampling effort. Insufficient sampling effort in inshore fisheries may result in significant underestimates of by catch rates. Although the scale of inshore fisheries around the Welsh coast is not large and some dedicated monitoring has already been carried out, the specific interest in bycatch in the southwest suggests that effort to monitor bycatch in these fisheries closest to breeding sites should be increased. Increased marine mammal bycatch monitoring on French, Irish and other EU registered vessels fishing in this region would also be helpful. The potentially large takes in the French and Irish fisheries mean that the bycatch rates presented above may significantly under-estimate the scale of the problem. See also Figure 4 (page 12) in Northridge *et al*. (2019) where levels of uncertainty in existing estimates of seal bycatch are mapped out based on where sampling has already been achieved. Welsh coastal waters and some offshore areas are highlighted as areas of high uncertainty, while the Bristol Channel has received very limited sampling to date.

Identifying the source of bycaught seals in the southwest is a priority. Samples suitable for DNA analysis are routinely collected from bycaught seals and have also been collected from grey seal pups at breeding sites in Wales with the help of NRW. Additional samples are required for breeding sites in Ireland and Western Scotland. This sampling in conjunction with ongoing work elsewhere to describe the grey seal genome in more detail should help us to determine the natal origin of the seals caught in nets. Progress on this issue will require substantial additional funding. SCOS consider this work should be a priority and should involve and build on existing collaborations between UK and Republic of Ireland researchers.

Tracking movements of juvenile grey seals from sites in the Inner and Outer Hebrides would also potentially provide estimates of migration rates into the southwest. A project to track a sample of pups from the Hebrides is planned for 2021 and should provide the required information.
The value of increased sampling of stranded seal carcasses under the CSIP is not limited to the bycatch issue. Information on causes of seal mortality and demographic parameter estimates obtained from such studies are important for improving our understanding of several aspects of seal population biology. Records of stranded seal carcasses are unlikely to provide robust estimates of bycatch rates because of the likelihood of carcasses washing ashore depends on the location of fishing activities (e.g. relative to currents and distance from shore), weather, and condition of seals at time of death.

Remote Electronic Monitoring (REM) on fishing vessels provides invaluable data on various aspects of fishing activity. Recording by-catch events will rely on video monitoring. For many aspects of fishing a subsample of the continuous video record will provide useful evidence. However, in most cases, the incidence of bycatch is low, e.g. Northridge *et al*. (2019) and Luck *et al*. (2020). Such rare events are notoriously difficult to estimate from sampled data and producing robust estimates of bycatch rates will likely require a large proportion of the video records from each vessel to be inspected by trained observers. If those resources are available, REM can produce accurate counts of bycatch. However, whether REM will produce more reliable or more cost effective data than those collected by observers is a moot point, and will depend on many variables including the initial set up costs of an REM operation, and the ongoing maintenance costs, and the nature of the fishing operations. Few and short fishing operations are easier to monitor using REM than many long operations. Studies in the US have shown that different fisheries with different operating practices show widely different relative costs for at-sea observations and REM observations. This question is therefore not a simple one to answer and would require a dedicated assessment.

Observers on fishing vessels are highly effective at recording bycatch, but have a cost attached to them. An economically attractive alternative might be to try to rely on self-reporting by fishers. However, it has been repeatedly shown that this is not a reliable way to estimate bycatch, most recently through the NAMMCO bycatch working group (NAMMCO, 2020).

Seals and Fisheries and Aquaculture

16. Can SCOS advise on what information is available to provide evidence of seal depredation in the UK and any seasonal / geographical hot spots where this is known to be a prominent problem? **Can SCOS also advise on how to further investigate and address this issue? To include an update on SMRU pursuing funds to explore this issue through information collected on seal-damaged fish recovered from nets (under bycatch monitoring scheme)?**	Defra Q5

SCOS is not aware of any new published quantitative information on the extent, frequency, intensity, or geographical pattern of interactions between seals and fishing operations and no quantitative information on rates of removals or frequency of seal damage to fish in gear. Complaints are received by Defra/MMO but there is currently no mechanism for these to be assessed by SCOS.

There is a perceived problem and suggestions that it is getting worse. Increasing seal populations in the central and southern North Sea and in the South West are likely to increase levels of interactions between seals and fisheries in England and Wales.

MMO (2020) published a report on a stakeholder engagement process involving online and telephone surveys of fishers' experiences and perceptions of their interactions with seals. Fishers consider this to be an increasing problem, but no quantitative information was presented to allow assessment of the scale or cost of depredation at any location/fishery and no information to allow identification of seasonal / geographical hot spots.

If DEFRA/MMO consider that the problem needs to be investigated, SCOS recommends that a UK wide workshop involving fisheries managers, local and national fisheries organisations and marine mammal scientists be convened to design a study, with the aim of defining the specific issues and

identifying locations and timings of interactions that warrant further investigation. Once specific problems have been identified, data requirements can be assessed, and appropriate research/monitoring programmes can be developed.

In 2018, 2019 and 2020 Defra/MMO have reported that there are increasing numbers of anecdotal accounts of seals causing considerable damage to fish that have been caught in nets and on lines at various locations on the English coast. The rapid and continuing increase in grey seal populations in the central and southern North Sea means that the existing problems are likely to get worse. However, SCOS is not aware of any structured programme to log and assess the validity of these reports, to quantify the scale of removals or estimate the economic cost or to identify trends in these metrics.

MMO (2020a) published a report on a stakeholder engagement process involving a workshop and online and telephone surveys of fishers' experiences and perceptions of the extent of, and trends in seal depredation. The report describes fishers' perceptions of increasing levels of predation and their belief that this is due primarily to the increasing seal populations in their areas. However, as there has not been a structured monitoring programme for recording seal damage or for collecting data on seal observations/seal sightings rates these reports do not allow quantitative assessments or comparisons.

A comparison of the at sea distribution of grey and harbour seals from SMRU's seal usage maps and a map of netting activity, was used to identify areas of "potentially significant overlaps between seals and netting activity" around the English coast (MMO, 2020a). No details of the method of comparison are provided, and it does not appear that evidence of interaction was included in the assessment.

For grey seals the areas identified were the north-east (specifically around Alnmouth), the east coast (around Great Yarmouth/Lowestoft and Southwold) and the south west (particularly the Isles of Scilly, Land's End and north Cornwall coast). For harbour seals the areas of potential overlap were identified as the north-east (specifically off Tynemouth) the east coast (around Great Yarmouth/Lowestoft) and the south-east (around Felixstowe and Sheerness, the Greater Thames Estuary, to Dover). SCOS noted that the concentration of harbour seals off Tynemouth is unlikely as few harbour seals occur along the NE English coast.

No new quantitative information on the effects of different fishing practices are available. The only significant, relevant study of the effects on different fishing activities of depredation is that of Cosgrove *et al*. (2013) based on observations on hake and pollock netting by Irish boats. Cosgrove *et al.* (2013) showed that soak time, depth, haul speeds and haul sequence, noise from fishing activity, season, day/night deployment, net type location, particularly in terms of distance to nearest concentration of seal haulout sites, all affect the extent of depredation. Fishers in the MMO surveys reported taking actions to reduce impacts that addressed several of these factors, including reducing soak times (i.e. the length of time between setting and retrieving fishing gear), moving to a different area, attending gear, reducing noises that may attract seals and adjusting rigging (for pots). However, they also reported that these methods were not effective long-term solutions as seals rapidly adapted to them.

The MMO (2020b) also reported a series of trials of the GenusWave startle response ADD in different configurations on bottom set tangle nets. Despite several technical faults leading to non-functioning devices or reduced output, the trials indicated an apparent increase in catch in nets with active ADDs. The reported effect size was large but with wide confidence intervals. However, catch was higher in the treatment nets in 23 of the 36 paired trials included in the analysis, indicating that the ADD did deter seal depredation. The MMO report highlighted the cost effectiveness of this method as a problem if it were to be recommended as a general net protection method.

SCOS recommends that a workshop involving fisheries managers, local and national fisheries organisations from the whole UK and marine mammal scientists would be a useful first step in defining the specific issues, locations and timings of interactions and identifying potential solutions that warrant further investigation. Once specific problems have been identified, data requirements can be assessed, and appropriate research/monitoring programmes can be developed.

The UK Protected Species Bycatch Monitoring Scheme has collected data for 20 years on the bycatch of marine mammals through on-board observations, some of which is associated with depredation. It has also collected information on seal-damaged fish recovered from nets. There has been no progress in obtaining additional resources to conduct a quantitative assessment of these data

17. Can SCOS advise whether there is a real risk of seal entanglement / mortality in aquaculture nets, and if so, whether this can be quantified?	MS Q8

SCOS is not aware of any systematic, verifiable records of seals drowning in ant-predator nets at Scottish finfish farms but there are many anecdotal reports and records from salmon farms in British Columbia show that 44 harbour seals drowned in nets between 2011 and 2020.

The problem may be reduced by using small mesh nets that pose a minimal entanglement risk if tensioned properly

SCOS noted that there is currently no reporting requirement for such entanglement events and suggest that there should be, to assess whether a problem exists and to provide information on the frequency and characteristics of entanglement events.

SCOS is not aware of any verified records of seals killed in anti-predator nets in Scottish aquaculture, but there have been anecdotal reports of sometimes large numbers of seals being drowned in anti-predator nets (Northridge *et al*., 2013). Entanglement was reported as a reason for not using anti-predator nets in a survey of anti-predator measures at Scottish finfish farms (Northridge *et al*., 2010) and is also reported through the seal licensing survey as a reason for not using anti-predator nets. There is currently no reporting requirement or independent monitoring for seal entanglement events and as a consequence it is neither possible to independently assess whether a problem exists nor to provide information on the frequency and characteristics of entanglement events. SCOS recommends that, at a minimum, reporting of seal entanglement events would be required to indicate if the issue occurs at all. Targeted monitoring might then be required to estimate the frequency of occurrence.

Reports of seals killed at aquaculture sites in British Colombia included a total of 44 harbour seals and 33 California sealions killed by “accidental drowning” between 2011 and 2020. These are assumed to be mostly killed in anti-predator nets (https://open.canada.ca/data/en/

dataset/a7b3fdfb-5917-4ca6-b29c-093e3f65d6ba). Northridge *et al*. (2013) noted anecdotal reports of seals being killed, in one incident up to 31 individuals, but at the time anti-predator nets were generally large mesh nets that are known to catch seals. Small mesh nets would reduce the potential for seal entanglement to very low levels, but that comes at a cost in terms of increased drag and fouling and reduced water circulation and may be impractical at some sites.

The mechanism of entanglement is unclear but may be related to insufficient tensioning of the anti-predator net. Systems have been developed in Canada, Tasmania and Chile to help reduce this problem, but it is not clear how applicable they would be to Scottish salmon farms.

18. In 2019 SCOS advised that there were no non-lethal measures available to remove seals caught within fish farm cages. Can SCOS advise on whether there has been further developments/technological solutions on this matter since their last advice?	MS Q9

SCOS is not aware of any existing non-lethal method for removing seals from cages. SCOS considers that preventing seals from entering cages through use of seal proof nets and effective barriers should be the standard method.

Seals do occasionally manage to enter fish cages at finfish farms and are then sometimes unable to escape. A seal in a fish farm cage is likely to damage large numbers of salmon and its presence will likely cause severe stress to the surviving fish. It is therefore essential to remove the seal as quickly as possible.

SCOS recommends that simple methods for rapidly forcing seals out of cages should be investigated. Two proposed methods were discussed but will need further development and testing.

SCOS recommends that a workshop, involving farm operators, net designers and marine mammal biologists with direct experience of these issues should be organised to combine existing experience of capture and release of a variety of pinniped species in similar situations.

The first line of defence should always be to ensure that seals cannot gain access to cages. Maintenance of seal proof cage nets, perimeter fences and potential methods such as electrified deck deterrents should be used where appropriate to minimize the likelihood of seals gaining access. Seals do occasionally manage to enter fish cages at finfish farms and are sometimes unable then to escape. A seal in a fish farm cage is likely to damage large numbers of salmon and its presence will cause severe stress to the surviving fish. It is therefore essential to remove the seal as quickly as possible.

These are rare events, but once inside a cage, a seal has the potential both to damage and kill a large number of fish rapidly and by damaging the net it may facilitate on-going escape of salmon. It is therefore imperative that whatever means are employed to remove the seal, they must be done quickly. Simply leaving the seal alone to find and use an available escape route may work eventually, but such a passive approach would leave the seal free to attack and damage fish and would likely be unacceptable to farm operators and would raise concerns from a fish welfare perspective. Attempts to drive a seal towards an escape route may prove difficult as a stressed seal in a cage is unlikely to behave cooperatively and it may not recognise the escape route. Deploying an ADD may force a seal to search for and use an escape route, but care would be needed to avoid potentially harming the animal in the process, and there is no guarantee that a distressed animal would find or use an escape route.

SCOS discussed the implications of leaving seals in cages for extended periods, for the UK's commitments as signatories of the NASCO (North Atlantic Salmon Conservation Organization). This requires the UK to minimise any escape of farmed salmon. Non-lethal methods for removing seals are prolonged then that could increase the likelihood of escape of farmed salmon. There may therefore be a conflict between a commitment for conservation of wild salmon, and a commitment to non-lethal methods to remove seals; a discussion involving relevant stakeholders is needed to resolve this conflict.

Providing an escape route for seals may seem appropriate but itmay be operationally difficult and would probably require re-engineering of the cages. Lowering a section of the barrier net to the surface level and providing an escape route is one option, although providing such an escape route for a seal that does not allow fish to escape would be difficult.

Catching seals in fish cages would be extremely difficult and potentially dangerous for both the seal and the farm operators. Although anaesthetic darting is a standard method for handling seals on land, anaesthesia in water poses a high risk to seals (including drowning) and is not standard practice. However, in the absence of other methods and in light of competing considerations, darting in the water may have to be considered.

A safe method for rapidly removing seals is therefore needed. Two possible methods are proposed here as possible practical solutions, but it must be stressed that these will require development and testing:

1. Floating deck to cause the seal to haul out. The simplest method would be to progressively cover the surface of the cage to make a floating deck, until only a small area of open water was available for the seal to surface and breathe. This could be achieved relatively easily using plastic floating pontoon cubes. Covering a 30 m diameter cage would require approximately 100 such cubes. Left alone, the seal would likely use the decking as a haulout and a sliding cover could then trap the seal on the surface and temporary fencing on the deck could be used to shepherd it towards an escape route, or to hold it until it could be caught and removed to another location. A trap mechanism to prevent the seal diving again after a breathing bout can be included in the design.
2. Fine mesh net trap. Employing a similar principle but using a small mesh net to cover the pool. Again, the seal would be constrained to breathe in a small, e.g. 1.5 m diameter, breathing hole. The net would need to then be submerged to a depth of approximately 2 m. Access to the surface would be maintained through a net tunnel that could be closed off to prevent it from diving again. The tunnel could then be detached from the main net and moved to an escape point where the seal could be released or removed to another location. Handling such nets with cages containing fish and a seal would be extremely difficult.

SCOS recognise that there may be alternative methods of capture and anaesthesia developed for other species, and different potential methods for trapping and handling seals within cages or methods for providing escape routes for seals that prevent fish escapes. SCOS recommends further investigation and as a first step suggests a workshop to bring together veterinary experts and fish farm operators with experience of dealing with pinnipeds in cages, to examine the feasibility of these options. Consideration should also be given to potential methods that allow seals to be extricated while allowing cages to be secured at the earliest opportunity to prevent escape of fish.

19. Drawing on the outcomes of the CES/MS review (non-lethal measures to address seal predation in fisheries/aquaculture) and the proposed NOAA guidelines, can SCOS advise what measures are available for fisheries to use to deter marine mammals? [To note that in doing so, it would be helpful if the practicality/feasibility/legalities of available measures could be considered] **Non-lethal seal mitigation measures in commercial fisheries: Can SCOS review the 2019 MMO report on non-lethal seal deterrents, the recently released NOAA guidelines to provide comments and recommendations on what the latest non-lethal mitigation devices, gear modifications and measures are to minimise seal depredation in commercial fisheries?**	MS Q10 & Q12 Defra Q3 (see answer 20)

Two reports, commissioned by Crown Estate Scotland (CES) and Marine Scotland, describing existing and potential non-lethal measures are currently under review. For information a summary of the CES non-lethal options report's findings, and a table detailing recommended methods are presented here. Both reports will be made available to SCOS as soon as they are published.

Coincident with the completion of the CES report, NOAA issued a proposed set of guidelines for deterring marine mammals, identifying both acceptable and specifically prohibited actions. The guidelines are open to public comment and a summary of the rules that will apply to phocid seals is presented below.

At the time of writing, reports of two co-ordinated studies relevant to this question are in the final stages of internal review. One details a study of the effectiveness of acoustic deterrence devices and other measures currently employed at marine finfish farms in Scotland. The other report reviews non-lethal measures for deterring seal predation on salmonids in rivers and at finfish farms and presents a set of recommendations of potentially useful existing measures and projects to develop and/or test novel methods (Thompson *et al.,* 2021). For information, a brief summary of the non-lethal measures review and a tabulated list of the recommendations are presented here and in Table 10. Many of the methods described for deterring seals in rivers and at finfish farms are applicable to open water marine fisheries.

Predation on salmon in rivers
It is clear from the available literature that there is no single, effective non-lethal solution to address the problem of seal depredation. There are however a range of methods that have been shown to have some success or have the potential to reduce predation.

Globally, the most widely employed methods are simple, low tech attempts to disrupt predation activity and to drive seals and sea lions away from parts of rivers or fishing activities where predation is concentrated. In general, harassment methods have not solved the predation problems, but are still widely used in the large salmon rivers and in inshore gill net and longline fisheries in the USA to disrupt pinniped foraging behaviour and where they are legal requirements prior to lethal removal. In Scottish rivers, attempts to actively move seals away from predation sites have involved relatively mild forms of harassment (e.g., shouting, hitting the water) compared to the methods routinely used in the USA. However, some of the methods employed in the USA such as cracker shells, aerial screamers and small hand-thrown pyrotechnics are widely used in the UK as bird scarers and therefore could potentially be used to increase the intensity of negative stimuli to move seals away from sensitive locations.

If all or a proportion of the seals attempting to swim up salmon rivers can be prevented from doing so, interaction with salmonids where they are most vulnerable would be reduced. A range of seal exclusion methods have been attempted or suggested:

- Physical barriers may provide a solution where they can be installed and maintained.
- Arrays of acoustic deterrent devices (ADDs) to produce acoustic barriers have shown promise in preventing seals entering or moving up rivers and may be the only option for preventing seals moving through the estuaries and lower reaches of larger salmon rivers
- Electric field barriers may prevent passage of seals, but results have been equivocal and additional testing would be needed before deploying a system.

If deterrence and exclusion methods have not worked or are not a practical option at a site, one potential solution might be to catch and remove the seals. However, translocating harbour seals (*Phoca vitulina*) and other pinniped species has been attempted in the USA and Australia but has not been successful. An alternative approach may be to catch seals and hold them in temporary captivity to remove the predation threat during important periods of the year e.g. during the peaks of the salmon runs or until the end of the fishing season (Thompson *et al*., 2021). This would be a large and complex undertaking and a briefing paper considering this and other potential methods will be presented to SCOS 2021.

Finfish farms
There is a continuing problem of seal depredation at Scottish salmon farms. Defence against such depredation is essentially a matter of dissuading seals from approaching and attacking the cages, or of making the cages seal-proof.

Measures to reduce the incentive for seals to attack cages include routine husbandry such as regular removal of dead fish and modification of the cage floor to include a seal blind. These are widely applied in Scotland.

Measures to make seal attacks less successful rely on a combination of:
- Maintaining the correct tension on nets to stop deformation in tidal currents and prevent folds and loose net that allow seals to get access to fish.
- Changing to new stronger and stiffer net types. The gradual uptake of new net materials is already having a significant effect in reducing the number of seals being shot at sites using the new nets.
- Using anti-predator nets (APNs). The use of APNs is gradually increasing in Scotland.

The primary method of deterring seals from attacking cages is the use of ADDs. Evidence of the effectiveness of ADDs is still equivocal, and a better understanding of their effectiveness remains a fundamental requirement. A Scottish Government/Marine Scotland commissioned study is examining available operational information on the extent and usage of ADDs at Scottish salmon farms with the aim of improving understanding of their effectiveness.

Where ADDs are used, a number of methods have been proposed to reduce the levels of noise input into the inshore marine environment and change the signal frequencies in attempts to reduce potential impacts on non-target species, including European Protected Species (EPS) such as harbour porpoises (*Phocoena phocoena*), bottlenose dolphins (*Tursiops truncatus*), minke whales (*Balaenoptera acutorostrata*) and killer whales (*Orcinus orca*).

Several ADD systems have been developed to reduce noise output at the frequencies most likely to disturb porpoises and dolphins. Other potential methods to reduce noise output involve reducing source levels and duty cycles, attempting to attenuate the ADD signals, restricting transmissions to times when seals are present and blocking transmissions whenever porpoises or dolphins are in the vicinity of fish farms. The latter options necessitate the development of sensitive seal. porpoise and dolphin detection systems.

In addition to direct deterrence using sound, Thompson *et al*. (2021) also address aversion methods including an electrified model fish that delivers a painful but not damaging electric shock and conditioned taste aversion methods.

Seal and cetacean detection systems
Active deterrence and seal capture methods, both in rivers and at finfish farms, either rely on or will be made more efficient by the timely detection of seals. Minimising the use of deterrents and targeting them only at times when seals are actively involved in predation or when they are at particular, sensitive locations, should reduce the likelihood of seals habituating to other deterrents and reduce the frequency and duration of disturbance to non-target species. The importance of the detection components of such detect-and-deter systems cannot be overstated.

Video systems designed for monitoring seals in rivers and at finfish farms are currently undergoing field trials and sonar systems have already been used to automatically monitor marine mammal activity around tidal turbines. Passive acoustic detection is widely used for monitoring small cetaceans, and recent developments in passive acoustic detection have enabled near real time monitoring of presence of baleen whales (Baumgartner *et al*., 2019 & 2020). Modification and further development of such systems, particularly the development and testing of detection algorithms should provide useful detection capabilities for both rivers and finfish farms.

Table 10. Summaries of available and potential non-lethal methods to deter predation by seals (reproduced from Thompson *et al.*, 2021).

Non-lethal methods for reducing seal depredation	System readiness	Development/research requirements	Estimated Costs	Effects on Non-Target Species (NTS) and Regulation
Direct harassment: (in rivers)	• A wide range of acoustic, visual, and tactile harassment methods are readily available, widely used and in some instances tested. • Limited evidence of short- or medium-term effectiveness. Testing has been sporadic. • Most methods may require effective seal detection systems (see below).	• Requires trials to assess effectiveness on grey and harbour seals in Scottish rivers. • Requires trials to assess impacts on salmonids. • Requires trials to assess impacts on non-target species, particularly EPS.	• Relatively low capital and operating cost. • But labour intensive and therefore expensive in terms of resources (e.g., staff).	• Some methods may require licensing (e.g., EPS and licences to disturb Schedule 1 birds). • It is illegal to deliberately injure seals. • Potential effects on migrating salmon. • Most projectile methods would not be acceptable in UK (as targeting the head would likely injure the seal).
Direct harassment: (at finfish farms)	• Not generally applicable.	• N/A	• N/A	• N/A
'Standard' ADDs as acoustic barriers: (in rivers)	• Wide range of commercially available devices. • Equivocal evidence for effectiveness, but potential solution for some rivers.	• Requires additional testing of ADD barriers to prevent movement upriver and methods for driving seals down-river. • Requires assessment of long term effectiveness. • Requires trials to assess impacts on non-target species, particularly EPS. • May require an effective seal detection system.	• Wide range of available devices: prices range from approximately £6000 upwards. • Some devices currently only available as rental packages. • Maintenance required for effective operation thereby requiring staff resources.	• Potential effects on non-target species therefore may require licensing (e.g., EPS) and mitigation. • EPS licence may be required for research purposes.
'Standard' ADDs: (at finfish farms)	• Widely used at Scottish finfish farms. • Wide range of commercially available devices. • Equivocal evidence for effectiveness. • Evidence for negative impacts on non-target species.	• Requires some combination of methods for reducing source levels, soft start, signal attenuation and triggered transmissions (see below). • May require effective seal detection systems (see below).	• Wide range of available devices: prices range from approximately £6000 upwards. • Some devices currently only available as rental packages.	• Evidence for effects on non-target species, including harbour porpoises, bottlenose dolphins and minke whales therefore EPS licences and mitigation required.

Non-lethal methods for reducing seal depredation	System readiness	Development/research requirements	Estimated Costs	Effects on Non-Target Species (NTS) and Regulation
		• May require effective cetacean detection systems (see below).	• Maintenance for effective operation, requiring staff time. • Costs of linked detector system unknown.	
Tailored signal seal ADDs – startle technology- (in rivers)	• System commercially available.	• Requires testing of tailored seal ADD barrier effectiveness in: ○ preventing seal movement upriver, ○ driving seals down-river, ○ Assess habituation and long-term effectiveness. • May require effective seal detection (see below).	• Systems available as part of rental packages tailored for each situation. • Maintenance required for effective operation requiring staff time. • Costs of linked detector system (where required) unknown.	• Potential effects on non-target species such as European otters and Eurasian beavers, therefore EPS licences and mitigation required. • EPS licence may be required for research.
Tailored signal seal ADDs – startle technology- (at finfish farms)	• System commercially available.	• Requires additional testing on non-target species. • May require effective seal detection (see below). • May require effective cetacean detection (see below).	• Systems available as part of rental packages tailored for each situation. • Maintenance required for effective operation. • Costs of linked detector system (where required) unknown.	• No empirical data on lack of effects for some non-target species, therefore may require an EPS licence. • EPS licence may be required for research.
Tailored signal seal ADDs – low frequency- (at finfish farms)	• Commercially available.	• Requires testing for effectiveness on target species. • Requires testing to assess potential effects on non-target species particularly low frequency cetaceans e.g. minke whales. • May require effective seal detection (see below). • May require effective cetacean detection in estuaries (see below).	• Systems available as part of rental packages tailored for each situation. • Maintenance required for effective operation requiring staff time. • Costs of linked detector system (where required) unknown.	• May impact low frequency cetaceans therefore may require an EPS licence. • EPS licence may be required for any research.

Non-lethal methods for reducing seal depredation	System readiness	Development/research requirements	Estimated Costs	Effects on Non-Target Species (NTS) and Regulation
Reduce ADD source level (at finfish farms)	• Already incorporated in some ADDs. • Relatively easy to implement in other devices.	• Requires targeted studies to assess effectiveness of reduced amplitude signals as seal deterrents, e.g. o to assess any reduced effect range; o to investigate whether there is an increased chance of habituation or toleration.	• No additional cost if using an existing ADDs.	• May impact low frequency cetaceans so may require an EPS licence. • EPS licence may be required for any research.
ADD soft start/Ramp-up (at finfish farms)	• Already incorporated in some ADDs. • Relatively easy to implement in other devices.	• Requires trials to assess the chances of habituation by seals. • Requires trails to assess the responses of non-target species to soft start, to assess actual/realised benefits.	• No additional cost if using existing ADDs.	• May impact low frequency cetaceans so may require an EPS licence. • EPS licence may be required for any research.
ADD signal attenuation, bubble curtains and baffling ADDs (at finfish farms)	• System tested and shown effective in protecting porpoises from piling noise. • Systems used to protect finfish farms from algal blooms in Canada could be effective as acoustic screens. • Bubble tubing commercially available and compressors already widely used on Scottish finfish farms. • Simple structures using foam screens as baffles around ADD transducers and strategic positioning of ADDs to	• Requires assessment of the technical and operational feasibility of air bubble curtains at finfish farms. • Requires trials of bubble curtains at operational finfish farms to assess the level of attenuation of ADD signals achievable in practice. • Requires trials of foam baffles and device placement at operational finfish farms to assess the level of attenuation of ADD signals achievable in practice.	• Bubble tubing to surround a typical 12 cage farm. would cost approximately £110,000. • In collaboration with finfish farm, initial trials could use existing compressors and airlines. • Experimental baffles relatively inexpensive. • Staff costs for field trials and measurement.	• Signals likely to fall below the sound threshold of regulatory requirements.

Non-lethal methods for reducing seal depredation	System readiness	Development/research requirements	Estimated Costs	Effects on Non-Target Species (NTS) and Regulation
	attenuate signals emanating from farms.			
New net materials (e.g. HDPE) (at finfish farms)	• Anecdotal but compelling reports suggest they are highly resistant to seal attack. • Already widely and increasingly used in Scotland.	• Collection and analysis of seal damage statistics for cages with existing and new netting materials.	• More expensive than existing nylon nets, currently approximately double the price.	• No negative impacts expected.
Anti-predator nets (at finfish farms)	• Already used in Scotland. • Insufficient data to assess effectiveness.	• Collection and analysis of seal damage statistics for cages with and without APNs. • Identification of measures employed in use of APNs in other countries and assessment of potential use Scotland.	• Material costs depend on type and sizes of cages to be protected. • Additional installation and operational cost.	• There may be potential issues associated with entanglement and drowning of seals. • There may be potential issues associated with entanglement and drowning NTS including diving birds and cetaceans.
Electric field barriers (in rivers)	• No off-the-shelf solution. Would need bespoke design and manufacture for each site. • Evidence for potential effectiveness.	• Requirement to assess the potential effect on migrating salmon and other NTS • Requires investigation of thresholds of response for food motivated seals. • Development of optimal array configurations. • Requires effective seal detector system.	• An expensive option. A single mobile field system is available at a cost of approximately £250,000.	• Potential health & safety risks • Potential for disturbance impacts on non-target species (e.g., beavers, otters, aquatic birds). • Requirement for EPS licence at some sites.
Non-lethal removal: translocation (rivers & finfish farms)	• Effectiveness unknown, e.g. likely rapid return but rate not estimated in UK seals or rivers. • Lack of efficient capture methods.	• Requires development and testing of methods for catching seals in rivers and at finfish farms. • Requires post release monitoring to assess effects of translocation, e.g. likelihood or speed of return and post release movements and behaviour.	• Significant staff resources required for capture and translocation activities. • Capital cost will depend on setting and equipment required – e.g. barrier net costs £500-£2500; cage trap & trigger system including CCTV costs £4,000-£5000;	• Licensing requirements would need to be determined as this has not been attempted commercially. Such a method would require a seal licence under the Marine (Scotland) Act 2010.

Non-lethal methods for reducing seal depredation	System readiness	Development/research requirements	Estimated Costs	Effects on Non-Target Species (NTS) and Regulation
			construction of river weir/barrier potentially high cost and entirely site dependent. • Requires specialist skills and experience.	• Initial trials may fall under the Animals (Scientific Procedures) Act 1986.
Non-lethal removal: temporary captivity (rivers & finfish farms)	• No existing seal holding facilities. • No captivity duration and release protocols. • Lack of efficient capture methods.	• Requires development of captive seal holding facilities/protocols etc. • Requires the development and testing of methods to catch seals in rivers.	• Cost heavily dependent on the availability of captive animal facility. • Requires specialist skills and experience. • Preliminary trials using a disused salmon finfish farm cage should be relatively inexpensive. • Seal maintenance (food, supplements, vet bills) costs per seal would be approximately £300 initial cost plus £15 per day plus staff costs. • Staff costs will depend entirely on the set up, e.g. whether as part of larger organisation or stand-alone facility.	• Licensing requirements would need to be determined as this has not been attempted commercially. Such a method would require a seal licence under the Marine (Scotland) Act 2010. • Initial trials may fall under the Animals (Scientific Procedures) Act 1986.
Conditioned taste aversion (at finfish farms)	• Effective CTA demonstrated in captive California sea lions but found to be ineffective in rivers No direct evidence available for grey or harbour seals. No existing protocols or methods of delivery.	• Requires trials with captive seals to assess CTA methods for grey and harbour seals, to develop appropriate delivery methods. • Requires field trials to assess practicality of the method.	• Significant staff resources for captive animal studies • Field application of baited fish would be low cost.	• Captive animal trials will fall under Animals (Scientific Procedures) Act 1986.

Non-lethal methods for reducing seal depredation	System readiness	Development/research requirements	Estimated Costs	Effects on Non-Target Species (NTS) and Regulation
		• Requires structured monitoring of use in practice to assess benefits of use.		
Conditioned aversion – electric fish (at finfish farms)	• Commercially available system exists. • Used alongside suite of other measures may enhance overall effectiveness. • Approach could be adapted to 'electrify' dead fish.	• Requires structured tests to assess effectiveness. • Requires development of method involving dead salmon as the electrified bait.	• Research with captive seals expensive. • Requires specialist skills and experience. • Application of electric fish at finfish farms currently available as part of integrated control package. • • •	• Licensing requirements would need to be determined. The effect is essentially the same as that in low voltage electric fences that are widely used in agriculture to control movements of both wild and domestic animals.
Non-lethal removal of seals trapped in finfish farm cages				
Anaesthesia & capture (at finfish farms)	• Methods for confining seals to a small area of the pool and darting with anaesthetic have been proposed. • Experience with wild seals cautions against this method, but groups in Canada and Australia are investigating possible methods.	• Recommend a workshop to bring together expertise on removing different species from cages and different restraining/anaesthesia methods.	• Workshop costs/ online meeting costs low. • Applying such methods would require specialist skills and experience.	• Initial trials may fall under the Animals (Scientific Procedures) Act 1986. • This would raise seal licensing considerations under the Marine (Scotland) Act 2010. • There may be other legislative requirements.
Restricted surface trapping methods (at finfish farms)	• No tried or tested methods exist, but simple procedures based on covering the water surface in a cage to constrain a seal are conceptually feasible.	• Consideration should be given to the practical feasibility of such methods. • Requires the design and testing of a floating deck of plastic pontoon	• Floating deck costs approximately £5,000. • Netting methods depend on developing a practical and safe method/design and costs will depend on the chosen design.	• Initial trials may fall under the Animals (Scientific procedures) Act 1986. • This would raise seal licensing considerations under the Marine (Scotland) Act 2010.

Non-lethal methods for reducing seal depredation	System readiness	Development/research requirements	Estimated Costs	Effects on Non-Target Species (NTS) and Regulation
		cubes, with a seal capture and retrieval net. • Requires an initial feasibility study of netting methods and careful design to avoid potential drowning risk to seals.	• Workshop costs dependent on number of participants and whether it is held online or in person.	
DETECTION SYSTEMS (for use in conjunction with the measures above, particularly to trigger deterrent and exclusion systems)				
Detection – High Frequency (HF) sonar. **(at finfish farms)**	• Commercially available devices. • Effective detection algorithms developed and tested for seals. • System already tested at a tidal turbine site and in a salmon river to detect marine mammals. • Limited range so not currently applicable to finfish farms. • Dual functionality: seal detection and fish counting.	• Testing of detection algorithms for seals in river environment with specific sonar devices. • Choice of system will depend on the site characteristics and the required capabilities, e.g. whether simple detection and identification or sophisticated target identification and tracking are required. • Very short range: may require work to constrain river channel which may affect salmon migration or enhance predation opportunities. • Detection algorithms for seals require test and possible modification/development.	• Costs will depend on the chosen system: ○ HF fish counting sonars can cost in excess of £100,000 (at time of writing), ○ a single HF multibeam sonar head can cost approximately £25-35,000 (at time of writing). • Installation costs will depend on the site, but for initial trials the cost of construction/installation of a temporary or mobile system would be relatively small.	• Potential audibility of sonar to cetaceans if used in estuaries leads to the possibility of disturbance. • Assessment of the likelihood of presence of cetaceans and the range of detectability will be required to determine whether an EPS licence is required. • HF sonar should not be audible to otters or beavers.
Detection – Low Frequency (LF) or Mid Frequency (MF) sonar **(at finfish farms)**	• Commercially available devices. • Detection algorithms developed for HF sonar potentially transferable to LF or MF sonar detection algorithms.	• Testing of detection algorithms for seals and possible modification/development. • Requires investigation of potential audibility of MF and LF sonar to cetaceans.	• Costs dependent on chosen system. Requires review of suitable systems from perspective of range and suitability. Commercial costs unknown at time of writing.	• Potential audibility of sonar to cetaceans if used in estuaries leads to the possibility of disturbance. • Assessment of the likelihood of presence of cetaceans and the range of detectability will be

Non-lethal methods for reducing seal depredation	System readiness	Development/research requirements	Estimated Costs	Effects on Non-Target Species (NTS) and Regulation
				required to determine whether an EPS licence is required.
Detection – surface video (in rivers & at finfish farms)	• One system close to market: ○ Detection algorithms developed for seals, ○ IR tested and can detect seals in darkness ○ Linked to ADD operation. • Other systems under development and testing. • Detection algorithms under development for search & rescue may be adaptable.	• Requires testing of commercial systems to assess target detection and identification accuracy. • Requires linked detect and deter system to be proven. • Development and testing of additional systems. • Assessment of algorithms developed for search and rescue and modified if appropriate.	• Commercial system costs not available at time of writing. • Cost of trial multi camera/IR system under test is approximately £10,000 (at the time of writing) plus £10,000 installation cost. • Software/ID algorithm development will depend on the system requirements specified.	• Licensing requirements would need to be determined, as well as compliance with data protection regulations (if the system has the potential to capture images of people).
Passive acoustic cetacean detection (at finfish farms)	• No off-the-shelf automated real-time detection system available.	• Requires initial feasibility study to identify potential solutions and test automatic cetacean vocalisation detectors.	• Costs will be determined by outcomes of the feasibility study.	• Licensing requirements would need to be determined for development or deployment of passive acoustic detectors

NOAA Guidance on non-lethal control measures

The requirement to adhere to the standards of the MMPA mean that the legal status of non-lethal control measures under US law is relevant to their use in UK waters and rivers. NOAA issue guidance on what are considered acceptable methods for deterring pinnipeds in the USA. A new set of proposed guidelines were published in August 2020 and at the time of writing are open for public consultation. In most cases, the methods are similar to the previous guidelines, but now include strict criteria for ADD use with an online tool to assess whether a particular ADD is likely to exceed the limits. An Infographic providing a summary of the proposed rules can be found at https://media.fisheries.noaa.gov/2020-09/FINAL%20Deterrent%20Fact%20Sheet%20%28508%29%209.4.2020.pdf

The guidelines also include additional controls on the use of both in air and underwater explosives, setting device specific minimum ranges and maximum repetition rates. There is also a specific prohibition on targeting the heads of pinnipeds when firing any type of non-lethal projectiles. This will prevent head trauma but will also make the use of such deterrents ineffective as generally only the head is visible when seals surface to breathe. Baton rounds (plastic or rubber bullets) that were in the previous acceptable deterrent list and were assessed are not mentioned in the rest of the document.

There is also a list of specifically prohibited measures which include “Feeding or attempting to feed a marine mammal in a manner prohibited by 50 CFR 226.3 even for the purposes of deterrence”. Such a prohibition would appear to ban conditioned taste aversion (CTA). No justification for this prohibition is presented in the documents. It is not clear whether CTA would be banned and if so why since it is a widely used therapy in human addiction treatments and is also widely used in controlling predation by coyotes and wolves in the USA and other countries.

The list is not exhaustive. Under the MMPA it is an offence to injure or kill a seal. The list is apparently designed to provide assurance that these methods have been agreed as being safe, so any injury or death of a seal caused during correct application of these methods will not lead to prosecution. The opposite is true for the prohibited methods, any injury caused while using methods is likely lead to prosecution. The status of un-named methods remains ambiguous. It appears that they can be used, but their use becomes illegal if they cause injury or death.
A summary of parts of the guidance relevant to deterring phocid seals is presented below. In the guidance these are divided into those applicable to ESA species, i.e. those listed under the US Endangered Species Act, and non-ESA species. In practice the acceptable deterrents are the same, and the designation is not relevant to UK seal species.

The proposed list of acceptable deterrents for use on pinnipeds in the USA is:

Non-acoustic methods.

Visual	Bubble curtains. Air dancers, flags, pinwheels, and streamers. Flashing or strobe lights. Human attendants. Predator shapes. Vessel patrolling. Unmanned Aircraft Systems.
Physical barriers	Containment booms, waterway barriers, and log booms. Gates or closely spaced poles. Horizontal bars/bull rails. Rigid fencing in air. Swim step protectors.

Tactile—Electrical.		Electric fencing (in air). Low voltage electric mats.
Tactile—Projectile[NA1].		Foam projectiles with toy guns. Paintballs with paintball guns. Sponge grenades with handheld launcher. Blunt objects with slingshot.[NA2]
Tactile—Manual.		Blunt objects—blunt tip poles, brooms, mop handles, etc.
Tactile— Water.		Water hoses, sprinklers, water guns.

Acoustic methods

Impulsive-explosives[A1]	underwater	Cracker shells, seal bombs, under-water firecrackers[A2].
	In air	Aerial pyrotechnics/fireworks. bird bombs, Bird bangers, bird whistlers/screamers, bear bangers, propane cannons.
Impulsive-non-explosives	underwater	Low frequency, broadband devices. Pulsed power devices
	in air	Banging objects in-air passive acoustic devices (e.g., hanging chains, cans).
Non-Impulsive	underwater	Acoustic alarms (i.e., pingers/transducers/ADDs)[A3] Predator sounds/alarm vocalizations using under-water speakers.
	in air	Air horns, in-air noisemakers, sirens, whistles.

Notes

NA1. No head shots are allowed, only the posterior of a seal can be targeted.
Paintballs and sponge grenades may only be fired from a minimum distance of 14 m from a phocid.

NA2. When using a slingshot (equivalent to a catapult in UK), a warning shot must be fired to land close to the seal before targeting the animal's rear. Strangely, no minimum distance is defined for blunt objects fired from a sling shot, despite the fact that such shots can be more damaging than a paintball or a sponge grenade.

A1. Explosive devices cannot be used if a cetacean is detected within 100m. Explosive devices must detonate behind the seal.

A2. minimum silent interval and minimum ranges defined for each type of banger when used against a phocid: 6 minutes and >3m for Cracker shells; three minutes and > 20m for seal bombs; 1 sec and > 2m for underwater firecrackers

A3. No acoustic transmissions ≥170 dB RMS are allowed.

In addition to the list of recommended methods there are also general prohibitions and a list of specific methods that are to be prohibited.

General prohibitions:

Targeting any deterrent action at a marine mammal calf or pup.

Striking a marine mammal's head or blowhole when attempting to deter a marine mammal.

Deploying or attempting to deploy a deterrent into the middle of a group of marine mammals.

Feeding or attempting to feed a marine mammal even for the purposes of deterrence.

Non Acoustic Methods which are prohibited are:

Patrol animals.

Vessel chasing.

Using any chemical irritants, corrosive chemicals, and other taste deterrents to deter marine mammals.

Sharp objects.

Using a firearm, except for bird bombs and cracker shells.

Acoustic Methods which are prohibited are:

Any impulsive explosives not included in the guidelines or specific measures.

Seal bombs, underwater cracker shells, bang-ing objects underwater, pulsed power de-vices, or low frequency broadband devices when visibility is <100m (e.g., at night, fog).

Any non-impulsive device with an underwater source level ≥170 dB RMS, unless that device has been evaluated and approved by NMFS or via the NMFS Acoustic Deterrent Web Tool.

20. Can SCOS provide advice as to what non-lethal measures are available to sea fisheries to address the depredation aspects of conflict between fisheries and seals, including inshore fisheries (e.g., rod and line caught mackerel)?	MS Q11
Non-lethal seal mitigation measures in commercial fisheries: Can SCOS review the 2019 MMO report on non-lethal seal deterrents, the recently released NOAA guidelines to provide comments and recommendations on what the latest non-lethal mitigation devices, gear modifications and measures are to minimise seal depredation in commercial fisheries?	Defra Q3 (see answer 19)

There are limited options for reducing depredation by seals through changes in fishing practices. Where they have been tried, none has been reported successful in the long-term.

Active seal deterrence is often proposed as an option and several active methods involving use of pyrotechnics and underwater impulsive sounds are potentially available. Such methods have not yet been shown to be effective anywhere.

Recent trials with acoustic startle devices on set nets and on mackerel line fishing boats have shown some initial promise although thorough analysis of the data from longer duration trials is ongoing and there may be concerns about costs.

There are two approaches to reducing conflicts between sea fisheries and seals. The first involves changing fishing activities to minimise the number and duration of interactions and thereby reduce the opportunities for seals to inflict damage. The second involves deploying some form of deterrent to disrupt seals' foraging activities or drive them away from the fishery (see Q20).

There are limited options available for reducing opportunities for interactions. As reported above, Cosgrove *et al.* (2013) showed that several aspects of fishing activity affected depredation and bycatch rates in bottom set nets for pollock 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. However, fishers who responded to the MMO (2020a) surveys reported taking actions to reduce impacts, including reducing soak times, moving to different sites, attending gear, reducing noises that may attract seals and adjusting rigging (for pots), but also reported that these methods were not effective long-term solutions because seals rapidly adapted to them.

In the UK there have been anecdotal reports of a range of methods being attempted to protect fisheries by driving seals away from fishing activities (MMO, 2020a), but few have been part of formal studies to assess effectiveness. As reported in answer 20, some of the acoustic harassment methods used in USA fisheries to deter seals and sealions, such as firecrackers and small seal bombs could be adapted for use in open water sea fisheries in UK waters. However, to date none of these methods has proven successful as long-term solutions (Thompson *et al*., 2021) although they are still widely used in US freshwater and inshore fisheries.

One possible solution is the use of acoustic deterrent devices. A series of trials with one device, the Genuswave TAST were carried out as part of the MMO non-lethal methods study (MMO, 2020b). Details are presented in answer 16 above. Results showed an increase in catch in bottom gill nets with the active devices.

The same device has recently been field tested in a line fishery for mackerel, off Rosehearty in the outer Moray Firth. Results from a preliminary two-day trial suggested that seal activity beneath the fishing vessels decreased and catch increased when the device was active. Results of a two-month trial conducted during late summer 2020 are being analysed and results will be reported to SCOS 2021. If successful, this may provide a means of reducing predation. However as pointed out by MMO (2020b) the cost of such systems may be prohibitive for small scale inshore fisheries

The MMO (2020a) reports on stakeholder engagement in the non-lethal control of seal interactions with fisheries were discussed in answer 16 above. The components of the proposed NOAA guidelines that are relevant to seal interactions with fisheries were discussed in answer 20 above.

21. Can SCOS advise on the efficacy of acoustic deterrent devices, including startle technology in deterring seals at aquaculture sites, without disturbing non-target species, including cetaceans? Can SCOS also advise on the potential for ADDs to have negative consequences, including injury to seals?	MS Q13

A Scottish Government sponsored study of ADD use will be published in 2021, but preliminary results suggest that there is insufficient information to assess the efficacy of ADDs. This highlights the need for more information,

Lower frequency and lower amplitude ADDs are now being used by a significant proportion of farms, which might have a lower impact on sensitive non-target species such as porpoises and dolphins.

There is clear evidence of the potential for disturbance of porpoises and minke whales from conventional ADD use. There is potential for hearing damage in seals, but this depends on the device characteristics as well as behavioural responses of seals to exposure. There is insufficient information on this to assess the likelihood of such injury.

Acoustic Deterrent Devices

A SMRU study for Marine Scotland on the extent of use and efficacy of ADDs is currently concluding, with a report under review to be released in early 2021. The aim of this study was to collate existing data on ADD use in aquaculture and fisheries, to provide a better understanding of their efficacy and any potential for impact on sensitive non-target species. Records were provided by a range of industry sources and regulators, and a database developed describing the extent of ADD use in Scotland from 2014 to 2020. Lower frequency and lower amplitude ADDs are now being used by a significant proportion of farms, which are likely to have a lower impact on sensitive non-target species, but the precise sound output varies greatly depending on the mode of operation and number of transducers in use.

Some data were also made available on the rate of depredation by seals in salmon aquaculture, and these were assessed against the database of ADD use, and supplementary data on alternative non-lethal measures. These data were observational, rather than coming from a controlled trial, and were found to be highly confounded - farms which experience seal depredation are more likely to use ADDs. A small number of sites were identified where the use of ADDs is prohibited, and methods were developed to use these as a de facto control sample. Statistical modelling was also used to assess changes in depredation rate where farms had varied the state of ADD use, post hoc. The quality of the available data was found to be low, and no evidence was found for the efficacy of ADDs.

This work has highlighted the paucity of evidence and available data, particularly for assessment of ADD efficacy in preventing seal depredation. Systematic data collection and controlled trials are urgently required, particularly in the context of the changing regulatory framework.

Potential for hearing damage to seals, both temporary and permanent threshold shifts as a result of cumulative exposure to ADD noise have been suggested (Goetz & Janik, 2013). Understanding the likelihood of such damage will depend critically on understanding the responses of individual seals to exposure to ADD signals. At present there is insufficient information to reliably assess the likelihood of damage to individual seals or to estimate the number of individuals of either species that are exposed to such risk. Todd *et al*. (2019) estimated potential disturbance ranges for existing ADDs and suggested that seals may be disturbed over wide areas of the West of Scotland SMU. However, harbour seal populations in this SMU has shown continuing growth (SCOS-BP 20/03).

The use of ADDs at finfish farms in large parts of the coastal waters around Scotland (Findlay *et al*., 2018; Todd *et al*., 2019), raises concerns about possible disturbance impacts on non-target cetacean species (Benjamins *et al*., 2018), all of which are listed as European Protected Species (EPS). The cetacean species of primary concern in Scottish waters are harbour porpoise, bottlenose dolphin, minke whale and killer whale. Several studies have extensively reviewed the deterrence effects of commonly used ADDs on cetacean species (e.g., Coram *et al.*, 2013; Sparling *et al.*, 2015; McGarry *et al.,* 2020).

Airmar and Lofitech ADDs have been shown to cause displacement of harbour porpoises out to ranges in excess of 3 km (Olesiuk *et al.,* 2002; Johnston, 2002; Northridge *et al*., 2010; Brandt *et al*., 2012a&b), although it's important to note that the Lofitech model is not used in aquaculture in Scotland. ADDs can emit signals loud enough to raise concerns about potential damage to porpoise hearing (e.g. Schaffeld *et al*., 2019). Less information is available for other species of concern in UK waters, but minke whales (Balaenoptera acutorostrata) and killer whales (Orcinus orca) have been shown to avoid signals from Lofitech and Airmar ADDs respectively (McGarry *et al.,* 2017; Morton & Symonds, 2002). Understanding of cumulative effects and population consequences of such effects is limited, which is an important information gap. A European Protected Species licensing system for ADDs is currently being developed which requires a cumulative assessment of the potential impacts on protected species.

Climate change

22. Is climate change likely to be having an impact on seals, and if so, how would the impact manifest itself?	MS Q13
Impacts on Seals through climate change: Can SCOS review latest scientific information available on current environmental impacts seals face due to climate change, such as acidification, sea level changes and coastal collapses and changing prey distributions.	Defra Q9

Climate change is already having a range of effects in UK waters, including changes to water temperature and salinity and is likely to change timing and intensity of stratification and locations and timings of fronts. Such changes will influence patterns of productivity and fish distributions and will affect prey availability to seals. These changes could have either positive or negative effects on seals in the UK.

Predicting the population consequences of climate change for seals is speculative. The uncertainty in the relationships between environmental drivers and seal population dynamics makes it unlikely that cause and effect will be reliably assigned to specific aspects of climate change. Observed trends in UK seal populations show growth mainly in southern parts of their range despite indications that distributions of currently preferred prey are shifting northwards.

There is uncertainty in the predicted effects of climate change on frequency and intensity of Harmful Algal Blooms (HABs) or on the effects of HABs on seals. However, the potential severity of HAB effects highlights the need for further research into HAB effects on seals.

Changes in sea level and resulting increased wave action may reduce breeding and haulout site availability in some areas and lead to increased wave action on breeding sites which can increase pup mortality, seals may be able to accommodate by moving breeding sites if alternative sites are available.

The seas around the British Isles, have warmed faster than the global average over the past 50 years. Sea surface temperatures (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). There are a wide range of interacting factors driving population change so it is extremely difficult to disentangle their effects and identify specific causes.

Most of the research on the impact of climate change on marine mammals has focused on the Arctic, where dramatic changes in ice volume and extent are already having profound effects on habitat availability. Changes in ice availability, and timing of freeze up and ice break up are already having direct impacts on ice breeding 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 forcing seals to breed on land, causing either direct mortality or reducing lactation efficiency and pup growth rates potentially as a result of water balance issues (Jüssi *et al.,* 2008; Hammill *et al*., 2013). Shuert *et al.* (2020) 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.

Changes in cold temperate waters, such as the seas around the UK, may also 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 seals. E.g. harbour seals occur in temperate coastal waters as far south as San Diego, California, and Brittany and the Wadden Sea in Europe where summer water and air temperature exceed those currently experienced by seals in southern England. Existing conditions at the southern limit of existing ranges are generally higher than projected temperatures in the UK over the next century even under high warming scenario predictions, but although harbour seals in other parts of their range experience higher summer temperatures, it is unclear what effects increased summer temperatures may have on terrestrial breeding behaviour and breeding success of harbour seals in the southern UK.

Prediction from status quo

Species distributions are not usually determined by physical capabilities alone. The distributions of both prey and competing predator species will influence the distribution of predators such as 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 UK 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.

Changing prey distributions.

The effects of climate change on prey distributions and changing patterns of fishing activity will both likely impact the distribution and population dynamics of seals. North Sea stocks of cod, plaice and haddock have shown northward shifts (Engelhardt *et al.*, 2011 & 2014; Skinner 2009). Recently, 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. 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, e.g. solenette (*Buglossidium luteum*), were consistent with the poleward distribution shifts expected from warming sea temperatures.

Atlantic populations of grey and harbour seals however have not followed this general 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 CoG. Similarly, for harbour seals in Europe, a southward shift in the CoG 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 this redistribution 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 of increased air and water temperature associated with climate change.

Harmful Algal Blooms (HABs)

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 species, but experimental studies of growth and survival rates of a range of species have suggested that HABs are likely to increase rather than decrease in the North Sea (Peperzak, 2003). Projections of sea surface temperature also suggest that the habitat of most species will shift north and may lead to more frequent harmful blooms 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.

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 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 values in the late 1980s in the northern and central North Sea areas. Dees *et al*. (2017) examined long term data sets from the North East 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 abundance and sea-surface temperature. 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.

Given this lack of consensus on the likely patterns of HABs and the uncertainty in the rates of consumption and likely levels of toxicity in seal diets, it is not possible to reliably predict the potential effects of climate related HAB changes on UK seal populations. However, the potential for such events to cause large scale mortality events means that further investigation is warranted.

Local oceanographic changes
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 (e.g. Wiltshire and Manly, 2004). Such changes have already been detected in the North Sea at several levels of the food chain. This may have knock on effects on the timing of prey availability that may impact on seal condition. Changes in flow patterns and 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.

Large scale oceanographic changes
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 as a result of anthropogenic forcing.
The AMOC is projected to weaken in the 21st century, although a collapse is very unlikely, weakening of the AMOC is projected to cause a decrease in marine productivity in the North Atlantic and an increase in storms in Northern Europe (IPCC, 2019).

Competition with fisheries
The climate driven changes will not only affect natural predators. The patterns of fisheries exploitation will also be affected. Current quota allocation structures will need to adapt to changes. How these changes are implemented is likely to have major implications in terms of prey availability for seals and other predators, and changes or re-distribution of fishing practices may affect issues such as bycatch.

Ocean 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 at, 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) have been shown to 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 & Rosenburg, 2008), and there is evidence (Queste *et al*., 2012) 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 populations (Pinnegar *et al.,* 2017).

Breeding habitat changes.

Predicted increases in sea level are small compared to the changes that grey and harbour seal populations have experienced due to sea level rise and iso-static rebound of the coastline since the last ice age. However, there is no reason to suspect that the availability of offshore islands, skerries, rocky shore or intertidal sand banks has decreased over that time or that availability will decrease, in the medium to long term, under projected sea level changes.

However, seal responses to previous sea level rises were not influenced by human activity patterns. In the face of future sea level rise it is likely that coastal defences will be maintained along large sections of coastline and particularly in estuaries. In such cases, because 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 would be more pronounced because a substantial proportion of the UK harbour seal population pup on intertidal banks in estuaries.

The UK State of the Climate Report 2019 (Kendon *et al.,* 2019) states that there are no compelling trends in storminess when considering maximum gust speeds over the last four decades. As there are no detectable trends there have been no studies that have so far shown a link between changes in UK storminess and climate change (Kendon *et al.,* 2019). However, in the short term, rising sea levels mean that storm surges and storm waves will increase the frequency and severity of wave action on breeding beaches. This will likely lead to increased mortality as observed in Welsh grey seal pupping colonies in 2017 (Buche & Stubbings, 2017). Such mortality events will likely increase in frequency and severity as sea levels rise.

Novel diseases
An additional concern is the spread of infection into regions where organisms may not have previously been exposed or where their capacity to survive may previously have been compromised due to unfavourable environmental conditions. With climate change, 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).

Renewable energy

23. Has there been any further progress on improving our understanding of how seals behave around tidal energy devices? And are we any closer to retiring collision risk, and if not, what further research is needed to achieve this.	MS Q14
Has there been any further progress on improving our understanding of how seals behave around tidal energy devices?	NRW Q2

Results of harbour seal tracking studies in Strangford Loch showed that seals avoided the operating tidal turbine but continued to transit through the channel passing the turbine. Transit rates were reduced during turbine operations. A recent study of harbour seal movement in the Pentland Firth show that they avoided the four-turbine array when it was operating, with reduced seal densities out to 2km range.

Wild, free-ranging harbour seals in Kylerhea also showed avoidance responses to a simulated tidal turbine noise signal.. Activity was reduced at ranges up to 500m during signal playback compared to silent control periods. SCOS noted that signals differ between devices so reactions to other turbines may differ.

Important data gaps still exist, e.g. the responses of seals to large scale arrays cannot be tested because there are no large arrays; there is little information on fine scale behaviour in the vicinity of turbines; all studies to date have been based on adult harbour seals and there is no information on the responses of grey seals or juvenile seals.

In the absence of information, particularly on array effects, SCOS are not in a position to determine when collision risk can be retired.

As reported previously to SCOS, empirical estimates of the degree to which seals avoid operational tidal turbines have been determined for the Strangford Lough turbine (Joy *et al.,*2018) and to playbacks of tidal turbine sounds (Hastie *et al.*, 2017; Robertson *et al.*, 2018).

Joy *et al.,* (2018) analysed GPS/GSM location data from tagged harbour seals (*Phoca vitulina*) and used a Brownian Bridge movement model to develop fine scale probability density surfaces for seal density in the 3x3 km2 region centred at the SeaGen tidal turbine before deployment and during operation of the turbine. Results suggested a mean spatial reduction in seal density of 68% (95% C.I., 37%, 83%) within 200 meters of the turbine, i.e. seals were 68% less likely to occupy habitat within 200m of the turbine.

Hastie *et al*. (2017) carried out a series of acoustic playbacks of tidal turbine sounds (SeaGen turbine) in a narrow, tidally energetic channel on the west coast of Scotland. Results showed there was a localised impact of the turbine signal; tagged harbour seals exhibited significant spatial avoidance of the sound which resulted in a mean reduction in the usage by seals of 27% (95% C.I., 11%, 41%) at the playback location. Wild, free-ranging harbour seals also showed avoidance responses to simulated noise for one tidal turbine. Activity was reduced at ranges up to 500m during signal playback compared to silent control periods. However, it was noted that signals differ between devices so reactions to other turbines may be different.

Robertson *et al.* (2018) studied the surface behaviour of harbour seals (measured from a land-based observation station) in response to acoustic playbacks of a tidal turbine (RivGen turbine) in Admiralty Inlet off the west coast of the US. The study reports that there were no significant differences in seal abundance or proximity to the sound source in response to the playbacks; however, the authors highlight that, due to markedly lower acoustic source levels compared to those used by Hastie *et al*. (2017), seals in their study would need to have been within 10 m of the playback location to experience similar received levels. Consequently, the authors suggest that the two studies (Hastie *et al.,*2017; Robertson *et al.,*2018) may actually be in agreement.

However, it should be highlighted that the observed responses were to a single point source and may not be appropriate for estimating the effects of multiple sources equivalent to operational tidal arrays. More recently, Onoufriou *et al.* (In review) carried out a study of the behavioural responses by tagged harbour seals to the presence and operation of the MeyGen array of four tidal turbines in the Pentland Firth, Scotland. Distributions of seals were compared before and after installation of the array, and between periods when the turbines were operating or stationary. The results showed that the presence of the turbine array did not significantly influence at-sea distribution but that the operational status of the array did. Model predictions suggested that seal presence decreased significantly up to 2 km from the turbine array during operational periods; mean change in usage within 2 km of the turbine was -27.6% (mean 95% CIs: -11% and - 49%).

A summary of the relevant results from previous studies is presented in Table 11. In practice, these empirical changes in abundance (Hastie *et al.,* 2017; Joy *et al.,* 2018) could be used directly to scale the animal density parameters when using collision risk models to predict the effects of tidal turbines on seals. However, this does not alleviate the need for data on potential close range- evasive action by individual seals which would further reduce the number of collisions.

Although good progress has been made in understanding how seals behave in response to operating turbine at scales of 100's to 1,000's of metres, information on the fine scale underwater movements (at a scale of metres) of individual seals around operating turbines remains the critical research gap with respect to understanding the potential impacts of tidal devices. However, some information on the behaviour of seals close to operating turbines could be available through further analyses of existing turbine mounted video recordings; preliminary analysis of a sub-sample of video data (between March 2016 and January 2017) from a turbine in the Nova Innovations Shetland Tidal Array has reported 13 sightings of harbour seals in close vicinity to (Nova Innovation Ltd 2020). Further, a NERC and Scottish Government funded research project is due to deploy a combined active sonar and passive acoustic tracking system alongside an operating tidal turbine in 2021. This aims to track individual seals in high resolution (metres) within 30 m of the turbine and quantify movements around the turbine. The combination of this and the results of the previous studies (Hastie *et al.,* 2017; Joy *et al.,* 2018; Robertson *et al.,* 2018) should provide information on behaviour of seals at the range of spatial scales required to derive empirical avoidance rates to operating turbines.

These measures of avoidance can be used to scale local population density data and improve estimates of numbers of seals at risk of collision. However, the accuracy of these predictions will be strongly influenced by the spatial resolution of the population estimates, which will often be based on strategic large-scale uniform density estimates rather than site-specific pre-installation datasets. Band *et al.* (2016) showed that the fine scale, at-sea distributions of seals was a major determinant of the number of seals at risk of collision and that ignoring fine scale distribution can both under and over-estimate the population at risk.

Other data gaps relevant to the impacts of tidal turbines on seals include the following: all studies to date have been based on adult harbour seals and there is no information on the responses of grey seals or juvenile seals; the absence of any large scale arrays means that there is no information on the effects of proposed large scale commercial arrays; accurate information on the individual and demographic consequences of disturbance is lacking. In the light of these large data gaps there is too much uncertainty in estimates of likely consequence to allow SCOS to comment on the potential or likely timescale for retiring risk.

Table 11. *Summary of the previous studies to measure the avoidance of operating turbines, or their sounds, by seals. The table shows the mean change in abundance (%), the tidal turbine and location of the study, the scale that a response was measured at, and the reference for the study.*

Mean % change in abundance	Source	Scale	Reference
-68% (95% CIs: -37%, -83%)	SeaGen turbine (Strangford Lough)	Within 200m	Joy *et al*. (2018)
-27% (95% CIs: -11%, -41%)	Acoustic playback of turbine sounds (Kyle Rhea, Skye)	Within 500m	Hastie *et al*. (2017)
No significant change	Acoustic playback of turbine sounds (Puget Sound, U.S.)	Within 1000m	Robertson *et al*. (2018)
-28% (95% CIs: -11%, - 49%)	MeyGen turbine array (Pentland Firth)	Within 2000m	Onoufriou *et al*. (In review)

Marine Plastics

24. Can SCOS review and provide an update on any new studies looking into how macroplastics, microplastics, abandoned (ghost) fishing gear and other plastic pollution are affecting seal populations? Is there a need for more research to be done on this subject area? Could such impacts be picked up in part under reporting of strandings and post-mortem work by CSIP?	Defra Q8

SCOS are not aware of any significant new information published since SCOS 2019, on the effects of macroplastics, microplastics, abandoned (ghost) fishing gear or other plastic pollution on seal populations.

The number of studies investigating the effect of microplastics, macroplastics, abandoned fishing gear and other forms of plastic pollution on seals is limited. Although there have been studies on discarded fishing gear and on the trophic transfer, retention and excretion of microplastics and ongoing research on the impact of plastic contaminants and plasticizers on UK seals, the

population consequences of these forms of marine debris have not been quantified so we do not know whether or not they are of concern. There are significant information gaps and current research will help shape future studies.

Both the CSIP and SMASS are collaborators and co-authors on recent publications on frequency of occurrence of plastics in seals. The strandings recovery and post-mortem work carried under these schemes is an essential part of ongoing studies.

Senko *et al*. (2020) recently reviewed the published information on individual and population-level effects of plastic pollution on marine megafauna. They conclude that, despite increased reporting of the extent and intensity of plastic pollution in the marine environment, and the well-documented effects on individuals, the extent and magnitude of demographic impacts on marine megafauna have not been addressed.

The specific issues raised in this question were addressed in SCOS 2019. SCOS is not aware of any significant developments in the field since the previous report. For information the previous answer is repeated below, with a modified description of ongoing work on the effects of plasticisers on seal physiology.

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

Microplastics (defined as plastic particles <5mm long) can be translocated across the gastro-intestinal membranes via endocytosis-like mechanisms (Alimba & Faggio, 2019) in invertebrates. They are also capable of adsorbing organic contaminants (such as persistent organic pollutants), metals and pathogens which will add to their toxicological profile as these will be in addition to their inherent plasticizer compounds. Nelms *et al. (*2019a) investigated the occurrence of microplastics in the gastrointestinal tracts of 50 marine mammals of 10 different species that stranded around the UK coast. Microplastics were ubiquitous: they were found in every animal examined but at relatively low numbers per animal (mean = 5.5) suggesting the particles were transitory. Stomachs contained a greater number than intestines, indicating possible temporary retention. However, only 3 grey seals and 4 harbour seals were included in this study. Nelms *et al. (*2019b) also found microplastics (1-5 pieces per gram of faeces) in 8 out of 15 grey seal scats (53%). The samples were all collected during the breeding season on Skomer Island off the Welsh coast, so they may only represent near-shore exposure. Nelms *et al. (*2018) showed that grey seals readily excrete microplastics in their faeces and feeding studies using polystyrene balls (3 mm) to determine fish otolith recovery rates, suggest that they all pass through the GIT within 6 days (Grellier and Hammond, 2006). Bravo Rebolledo *et al. (*2013) analysed 107 stomachs, 100 intestines and 125 scats of harbour seals from the Netherlands for the presence of plastics. They reported the occurrence of plastic in 11% of the stomachs, 1% of the intestines, and 0% of the scats. Hudak & Sette (2019) found anthropogenic micro debris (<500 µm) including cellophane, alkyd resin and EPDM rubber in 6% of harbour seal and 1% of grey seal scats collected at haulout sites on Cape Cod. Massachusetts, USA.

Whilst microplastics may be readily excreted by seals, retention in the stomach and intestine prior to egestion may facilitate the release of the chemical compounds and plasticizers during the digestive process. Toxicological impacts of microplastics for seals have not been reported in the literature at either the individual or population levels.

A joint project involving Abertay University and SMRU is investigating the effects of a group of plasticisers; the phthalates (in the form of benzyl butyl phthalate or BBP) on the insulin signalling pathway, an important regulator of fat metabolism in seals that inhibits lipid release from storage (Bennett *et al.,*2015), and expression of key fat metabolism genes in blubber using a novel *in vitro* approach (Bennett *et al.,* 2017). The project is currently using a novel *in vitro* approach to test whether activation of one of the key enzymes in insulin signalling, known as Akt, is affected by BPP exposure (Bennett *et al.,* 2017). Changes to Akt levels or its activation in the presence of insulin will imply disruption of insulin signalling. Differences in fat metabolism gene expression between BBP treated and control blubber explants will indicate disrupted fat tissue function

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

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

While individual effects of entanglement have been widely reported, extrapolating from such observations to estimate population scale mortality rates has not been possible. Sightings of entangled individuals, or seals with serious injuries, may not be representative of the frequency of occurrence in the population as the sightings could potentially be biased in either direction depending on whether entangled seals are more or less likely to come ashore. Likewise, strandings of seals killed by entanglement will be under-represented as few seals killed more than a few kilometres offshore will be likely to strand and entangled seals are more likely to sink. Although it is not clear what the population scale effects of entanglement are, there are examples where entanglement in discarded nets have had significant effects on local populations.

Seal Welfare

25. Seal Disturbance on beaches (animal welfare concern): **Can SCOS advise and provide seasonal and geographical mapping (within SoS waters) of current haul out sites where seal disturbance by members of the public is of most concern?** **Can SCOS advise and review latest scientific evidence on impact of seal disturbance and potential code of conduct measures that could be implemented to avoid seal disturbance by member of**	Defra Q11

public on beaches? **Are there best practice examples from other countries in terms of measures to control disturbance (e.g. Regulations, protected sites and/or codes of conduct).** **What would SCOS recommend in each of the devolved nations (given that Scotland have different legislation in place and have already designated nationally important haul out sites).**	

SCOS is not able to provide the requested advice on seasonal and geographical mapping (within SoS waters) of current haul out sites where seal disturbance by members of the public is of most concern due to a lack of the data required to inform such a mapping exercise.

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

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

As far as SCOS is aware, there is no formal or co-ordinated nationwide reporting system for recording disturbance events. Such a system could provide information to assess the effects of disturbance on local population dynamics or local haulout site use. Local site managers and NGOs have developed their own guidelines and, in some cases, they monitor disturbance events.

There is no formal licencing or recording system for swimming encounters with seals. NatureScot's guide to best practice for watching marine wildlife states that swimming with seals is not considered best practice and highlights that seals are large wild animals that are potentially dangerous.

Swimming with any seals poses a clear bite risk and health risk. Seals bites can cause Seal Finger a dangerous infection (probably due to *Mycoplasma phocacerebrale*), that can lead to severe necrosis and requires urgent medical attention and specific antibiotic treatment. The fact that large male grey seals are known to be predators of other marine mammals means that they pose a particular risk.

There are annual air surveys of the majority of haulout sites on the east coasts of England and Scotland during the annual harbour seal moult in August. There are also comprehensive surveys of all haulout sites around Scotland on a roughly five yearly cycle (SCOS-BP 20/03). However, there are only sporadic and incomplete summer surveys of the rest of the English and Welsh coasts. It is therefore not currently possible to derive a comprehensive list of the locations or the relative sizes of haulout sites for the UK coastline between Dover and the Solway Firth. No comprehensive surveys exist for any coasts at any other time of year, so it is not possible to describe seasonal patterns in the haulout distribution or the relative abundances of seals around the entire coast. Some large haulout sites in East Anglia and eastern Scotland, and several sites in Cornwall, Wales and north-west England are regularly monitored, so seasonal patterns at those sites are known. In Scotland ministers are required to designate important haulout sites under section 117 of Marine

(Scotland) Act 2010. It is an offence under the Act to deliberately or recklessly harass a seal on a designated haulout site. At present 194 sites are designated, but even here the designations of most sites are based on single summer counts repeated at 4-5 yearly intervals

It is also not possible to provide estimates of the level of disturbance to most sites. As far as SCOS is aware, there is no comprehensive monitoring scheme for recording disturbance to seals on haulout sites, at a national level or even at a local level in most regions. Even in Scotland where there is a specific law to protect seals at designated sites, there is no formal monitoring of those sites. Therefore, it is difficult to provide an answer to the specific question regarding whether this legislation helps to reduce seal disturbance. There are NGO led regional (e.g. Cornish Wildlife Trust's disturbance reporting scheme) and local (e.g. Ythan seal watch and Friends of Horsey Seals recording programmes) disturbance monitoring/reporting schemes (e.g. Cornwall Seal Group. 2019), but at present the pattern of disturbance even at regularly visited sites is only available through sporadic and anecdotal reports.

It is also not possible to provide a robust assessment of the importance of any disturbance that occurs, as the effects of human activity on seal haulout behaviour vary dramatically between regions and even between individual sites within regions.

The populations of both grey and harbour seals are increasing in the central and southern North Sea, in an area with a very dense human population, significantly increasing the opportunity for human seal interactions. Environmental tourism is also increasing rapidly in the UK, and seal watching is a rapidly growing sector. There are thriving seal tourism industries at various sites around the UK coast and at most sites that are visited by organized seal tourism ventures, the numbers of seals are increasing. There are now clear examples where obvious human presence, in some cases involving close approaches to seals, is not acting as a deterrent to hauling out (e.g. Horsey) or breeding (e.g. Blakeney and Donna Nook) by grey seals. Philipp *et al. (*2016) recorded repeated, frequent approaches by tourists to less than 30m from hauled out grey and harbour seals without overt signs of disturbance. It is also apparent that hauled out seals of both species can habituate to the presence of, and tolerate close approaches by tourist boats, e.g. tourist boats at Dunvegan, the Farne Islands and Blakeney Point now regularly approach to within 20-30m of seals on haulout sites without causing apparent disturbance response. The ability of seals to habituate to even severe visual and acoustic disturbance is shown by the presence of large haulout groups within the active military firing and bombing ranges on the east coast (Wash, Moray Firth, and Dornoch Firth). Conversely, there are regular press and social media reports of repeated disturbance of seal haulout sites and growing concern among NGO groups that such disturbance will negatively impact individual seals and pose potential threats to the continued use of sites for hauling out and/or breeding (Cornwall Seal Group 2019).

It is not clear that many haulout sites have been abandoned as a result of disturbance and there are clear examples of haulout sites persisting despite high levels of activity by members of the public or by industrial or military operations. In Cornwall in particular, but also in Northumberland there are concerns that seals may be injured if they are suddenly disturbed on rocky shore haulout site. There have been several distressing videos posted online of seals jumping from high tide haulout sites and crashing heavily into boulders on landing as a result of being disturbed by human activity. It is likely that some of these seals are injured as a result.

Other than direct injury, it is not clear what costs are involved for seals that are disturbed off haul outs. Paterson *et al.* (2019) showed that harbour seals disturbed from haulout sites either hauled out again shortly after the disturbance or went off to sea on what appear to be normal foraging trips. The rates of switching to different haulout sites after disturbance events were not significantly different to the rates of transition after undisturbed haulout periods. However, these were boat-based disturbances and land-based disturbance may have a more pronounced negative effect. Disturbance at breeding sites can lead to abandonment of pups in both species. If this is permanent and occurs relatively early in the lactation period, the pups will die of starvation. Such disturbance could constitute an offence under both UK and Scottish legislation. However, relatively short, sporadic disturbance of mother pup pairs may have little impact on pup survival as evidenced by the extensive research programs on grey seal breeding colonies in the UK and Canada and harbour seal pup tagging studies (Hanson *et al*., 2013).

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

Specific guidance on the offence of harassment at seal haul-out sites in Scotland has been published[10] Although such restrictions do not apply in the rest of the UK, guidance on general seal watching has been published by the Marine Management Organisation[11] and information notes on the effects of wildlife watching and non-motorised boat based disturbance on seals at haulout sites have been published by Natural England[12]. Guidance notes to provide advice on best practice for wildlife watchers and wildlife tourism operators have been published by both government and voluntary organisations (e.g. Scottish Natural Heritage[13], National Trust[14], Cornwall Seal Group[15]). All these guidance notes advise similar caution when viewing seals, with the aim of avoiding disturbance by observers approaching too closely. It is difficult to define best practice for seal watching in general because circumstances vary so much between sites. There is clear evidence that seals react differently in different locations, e.g. seals at Horsey and Donna Nook appear to tolerate close approaches on foot without overt signs of disturbance and seals at some sites in Skye, at the Farne Islands and at Blakeney Point allow close approaches by seal watching vessels that would cause severe disturbance at other sites. Also the types of potential disturbance will vary from place to place, e.g. visitors may arrive on foot or by boat, as part of organised wildlife watching cruises or as individuals or small groups, may be visiting primarily to see seals or may be involved in some other coastal activity. The advice at each site may therefore need to be tailored to local conditions.

There is now an established UK national training scheme for minimising disturbance to marine wildlife. The WiSe Scheme[16] *(WildlifeSafe)* aims to promote responsible wildlife-watching, through training, accreditation and raising awareness through a simple modular training course aimed primarily at wildlife cruise operators, dive and service boats and yacht skippers. The WiSe training scheme provides specific advice and guidance about approaching seal haul outs by boat, including awareness of signs that seals are becoming disturbed. An approach distance of no closer than 50 m is recommended.

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[10] https://consult.gov.scot/marine-environment/ /user_uploads/guidance-on-the-offence-of-harassment-at-seal-haul-out-sites.pdf

[11] https://marinedevelopments.blog.gov.uk/2016/08/11/seals-protected-illegal-touch-feed/

[12] Natural England Evidence Information Note EIN028 & EIN030

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

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

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

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

Recent guidance and advice aimed at the general public (e.g the recent 'give seals space' campaign available at: https://www.cornwallsealgroup.co.uk/2021/04/give-seals-space/) has been focussing on observing seal behaviour, being aware of what disturbance looks like and modifying your behaviour if signs of disturbance are evident.

SCOS is not aware of any information that allows a direct assessment of the efficacy of the designated haulout regulations in the Marine (Scotland) Act 2010, this issue is addressed in answer to Q9.

Swimming with seals, usually grey seals, has become a popular activity at certain sites around the UK. To date there have been thousands of such encounters, both as part of deliberate swim with seals programmes and incidental encounters as part of normal leisure diving activities. There are no estimates of the numbers of such encounters, but they will number in the hundreds or thousands over the past 20 years (Van Neer *et al.,* 2017) and such encounters have so far been generally benign. Scheer (2020) observed experimental seal-swim activities in Heligoland, recording 26 in-water encounters. Although the majority of interactions were classed as non-risky behaviours, risky behaviours, i.e. when there was physical contact or abrupt movements towards swimmers at close range (≤1 m), occurred during 73% of all seal-swims.

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

26. Can SCOS provide advice on currently available methods for lethally removing known (individual) seals. The information provided for each method should consider the following factors: animal welfare (how humane the approach is), the practicalities/feasibility and what resources would be required (including costs).	MS Q16

If lethal removal is required as part of a seal management strategy there are currently only three options:

- **shooting of free-ranging seals followed by verification of death,**
- **seal capture followed by lethal injection,**
- **seal capture followed by shooting.**

There is limited and potentially biased information on the welfare implications of shooting, but from limited data available it is clear that a proportion of shot seals were not killed instantaneously. Ballistics studies suggest that .308 rifles should be the minimum calibre weapons for shooting seals but acknowledge that, in many circumstances, weapons delivering lower muzzle velocities are effective at rendering the animal immediately unconsciousness.

Shooting free ranging seals in Canada requires a 2nd stage of verification of death involving palpating the skull/bleeding out. A requirement that seals should not be shot without a feasible method to rapidly retrieve the carcass would ensure as far as possible that seals are dispatched quickly.

The lack of effective seal catching methods both in rivers and at sea, limits the application of other methods. Both lethal injection and shooting of restrained animals are potentially effective methods, but to do so would require the involvement of specialist veterinary expertise to protect human safety and animal welfare. Catching, handling and transporting of seals does induce fear and distress, and is therefore a welfare consideration.

It is difficult to directly compare the welfare aspects of shooting free ranging seals with the welfare aspects of capturing seals before lethal injection or shooting. In one case an unknown proportion of seals may suffer severe pain and drowning in the other case all seals will be subjected to the stress effects of capture and handling.

SCOS-BP 20/07 gives further details of the available options in Scotland.

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ANNEX I Terms of Reference

NERC Special Committee on Seals

Terms of Reference
1. To undertake, on behalf of Council, the provision of scientific advice to the Scottish Government and the Home Office on questions relating to the status of grey and harbour seals in British waters and to their management, as required under the Conservation of Seals Act 1970, Marine Coastal and Access Act 2009 and the Marine (Scotland) Act 2010.
2. To comment on SMRU's core strategic research programme and other commissioned research, and to provide a wider perspective on scientific issues of importance, with respect to the provision of advice under Term of Reference 1.
3. To report to Council through the NERC Chief Executive.

Current membership

Dr M. Hammill (Chair)	Maurice Lamontagne Institute, Canada.
Dr C.E. Sparling	Sea Mammal Research Unit, University of St Andrews.
Dr J. Armstrong	Marine Scotland, Science, Aberdeen.
Dr M. Biuw	Institute of Marine Research in Norway. Tromso.
Dr G. Engelhard	Centre for Environment Fisheries and Aquaculture Science, Lowestoft.
Professor B. Wilson	Scottish Association for Marine Science, Dunstaffnage, Oban
Dr J. London	National Marine Mammal Lab. Seattle.
Dr K. Bennett	Abertay University, Dundee.
Dr O. Ó Cadhla	National Parks and Wildlife Service, Ireland.
Dr K. Frior (Secretary)	UKRI Natural Environment Research Council, Swindon.

ANNEX II Questions to SCOS.

Questions from Marine Scotland
Organisation: *Scottish Government*

Scottish Government Questions – Special Committee on Seals - 2020

Question	Driver/rational behind question(1-2 sentences)
Seal populations	
1. What are the latest estimates of the number of seals in Scottish waters?	General update on the estimated numbers of grey seals and harbour seals in Scottish waters.
2. What is the latest understanding about the population structure, including survival, reproduction and age structure, of grey and harbour seals in European and Scottish waters?	Information about the structure or make up of these populations that might assist management measures.
3. What are the latest SAC relevant count/pup production estimates for the harbour and grey seal SACs, together with an assessment of trends within the SAC relative to trends in the wider seal management unit/pup production area?	To provide current SAC specific estimates/trends for consideration in HRA assessments.
Harbour seal decline	
4. Is the existing harbour seal decline recorded in several local areas around Scotland continuing and what is the position in other areas?	Information on the latest trends in local harbour seal populations around Scotland to inform management measures.
5. In the 2019 advice, SCOS provide a view on the current potential (major) drivers of the harbour seal decline and their status. Can SCOS provide an update on these now that some of the ongoing work streams have completed?	Seeking clarity on the potential drivers that require further effort, in order to consider the need for any conservation and management measures
Potential Biological Removal	
6. Can SCOS provide updated Potential Biological Removals (PBRs) figures for 2021?	This seeks an update on the PBR figures.

Seal and fisheries interactions 7. In the 2019 advice, SCOS provided a bycatch estimate for grey seals in UK waters, although the estimate were largely based on observed rates from sampling focused in a particular region. Can SCOS advise whether there are potential fisheries or areas where bycatch could be a concern and which would benefit from extra sampling in order to increase confidence in the bycatch estimates? 8. Can SCOS advise whether there is a real risk of seal entanglement / mortality in aquaculture nets, and if so, whether this can be quantified? 9. In 2019 SCOS advised that there were no non-lethal measures available to remove seals caught within fish farm cages. Can SCOS advise on whether there has been further developments/technological solutions on this matter since their last advice?	 To understand the potential for impact of bycatch on seal populations and inform any future requirement for monitoring. To inform considerations of bycatch reporting and monitoring. In light of the potential implications of the MMPA, it would be useful to understand options for the non-lethal removal of seals from fish farm cages.
Nonlethal management measures 10. Previous SCOS advice has concluded that a lot of work done to date on non-lethal management measures, primarily in in rivers and aquaculture, are either far from a complete solution, impractical or have undesired effects on other species, with no specific method other than new netting material (for aquaculture) identified as a potential solution. Instead, SCOS advise that a structure research programme is required to fully investigate the practicalities of such approaches. Please can SCOS advise what such a research programme would consist? 11. Can SCOS provide advice as to what non-lethal measures are available to sea fisheries to address the conflict between fisheries and seals, including inshore fisheries (e.g., rod and line caught mackerel)? 12. Drawing on the outcomes of the CES/MS review (non-lethal measures to address seal predation in fisheries/aquaculture) and the proposed NOAA guidelines, can SCOS advise what measures are available for fisheries to use to deter marine mammals? [To note that in doing so, it would be helpful if the practicality/feasibility/legalities of available measures could be considered]	 It is important to identify non-lethal options that we can advise industry to consider using for seal control in the absence of lethal measures. NOAA have issued new guidance for safely deterring marine mammals, that Scotland will need to consider, including the practicality/feasibility/legalities of available measures.

Acoustic Deterrent Devices 13. Please can SCOS advise on the efficacy of acoustic deterrent devices, including startle technology in deterring seals without disturbing non-target species, including cetaceans? Can SCOS also advise on the potential for ADDs to have negative consequences, including injury to seals.	Need to find alternative ADDs that do not result in the disturbance of cetaceans or impacts on seals.
Climate Change 14. Is climate change likely to be having an impact on seals, and if so, how would the impact manifest itself?	To understand the potential for climate change to impact on Scottish seal populations.
Renewable Energy 15. Has there been any further progress on improving our understanding of how seals behave around tidal energy devices? And are we any closer to retiring collision risk, and if not, what further research is needed to achieve this.	To address a key barrier to the consent of tidal turbines / tidal turbine arrays.
Seal Welfare 16.Can SCOS provide advice on currently available methods for lethally removing known (individual) seals. The information provided for each method should consider the following factors: animal welfare (how humane the approach is), the practicalities/feasibility and what resources would be required (including costs).	Marine Scotland is currently considering whether shooting is the most humane method (in terms of animal welfare) to lethally remove seals for the purpose of (1) alleviating suffering or for the protection of public safety as fish farms, and (2) removing individual seals in rivers for the purpose of conserving a declining wild salmon. It is therefore important that we have an understanding of all methods available (e.g., shooting, chemical euthanasia etc.) to inform these considerations.

Questions supplied by Defra & compiled by *Victoria Bendall (Defra), Farah Chaudry (JNCC), Rebecca Walker (NE) and Rachel Wright (MMO).*

Question No.	Ongoing Questions: Required by policy and conservation advisors to be reviewed, summarised & updated annually if new information available.	Policy Driver/rational behind question:
1	**Seal Population Estimates:** What are the latest estimates of the number of seals in English waters? Are trends in harbour seal abundance still stable or increasing in English waters? Can SCOS committee review and advise on most robust methods/terminology for seal ground counts currently used to understand whether recent work (funded by NE) would be suitable for possible future inclusion in population estimate modelling?	General update on information regularly provided by the Committee in previous years but relating to seals in English waters. Monitoring and reporting of grey seal pupping sites in Cornwall in 2016 and 2019-2020 has recently been completed (funded by NE) to try to understand the numbers of grey seals pupping in caves compared to those pupping on beaches in SW England. The work explored whether most of the Cornish coastline could be covered by cliff-based counting. Results from two years of cliff based vs sea based surveys have shown different results, but overall conclusion is that clifftop surveys have the potential to count the majority of pups in all but the most remote locations (the Lizard).
2	**Seal Population Structure:** What is the latest information about the population structure, including survival and age structure, of grey and common/harbour seals in English waters and is there any new evidence of populations or sub-populations specific to local areas?	General update on information regularly provided by the Committee in previous years but relating to seals in English waters. There is a need for greater understanding of localised populations, to deliver more targeted conservation and management.
Question No.	**Emerging Issues Questions: Required by policy and conservation advisors based upon latest emerging issues for seals**	**Policy Driver/rational behind question:**

3	**Non-lethal seal mitigation measures in commercial fisheries:** Can SCOS review the 2019 MMO report on non-lethal seal deterrents, the recently released NOAA guidelines to provide comments and recommendations on what the latest non-lethal mitigation devices, gear modifications and measures are to minimise seal depredation in commercial fisheries?	Based upon recent government action to prevent the intentional or reckless killing of seals in English, Welsh and Northern Irish waters as a result of commercial fishing (schedule 9 of the Fisheries Bill Amendments, which will be effective from 1st March 2021. The amendments aim to address animal welfare issues whilst ensuring that UK fisheries exports are compliant with the US Marine Mammal Protection Act, thereby maintaining access to a key market. Defra are looking to work with industry on which non-lethal deterrents warrant further research and development for UK fisheries, to help mitigate any negative impacts of this otherwise positive step. We therefore require SCOS to help identify device(s) and/or practises that we can advise industry to use for non-lethal seal control. The MMO is looking to potentially extend the study by testing Acoustic Startle Devices in other areas/with other gears. A decision on funding from DEFRA will be made shortly to help mitigate changes to legislation.
4	**Seal Bycatch monitoring requirements:** What is the latest information on levels of seal bycatch across the UK? Are there particular seasonal and / or geographical hot spots of high seal bycatch? Are there any areas where it has not been possible to collect seal population/bycatch data? Can SCOS also provide advice on how to collect additional information on seal bycatch for UK? For example, could SCOS recommend the value of increased reporting of seal stranding's and post-mortems through CSIP? Advise on the value of Remote Electronic Monitoring (REM) on fishing vessels, the potential value of voluntary bycatch data recording by fishers (Noting that this is a Defra	Understanding levels of incidental wildlife bycatch in commercial fisheries is vital for improved clean catch fisheries management measures. It is important that we understand the scale and distribution of the problem so we can look at appropriate mitigating measures, if needed, particularly in light of recent Fisheries Bill amendments. Defra are looking to work with industry, scientists and eNGOs on a new project "Clean Catch UK: Joint Action to Reduce Wildlife Bycatch", a forward-looking national approach to monitoring and mitigating bycatch in the UK – driven by the Fisheries Bill and new National Plans of Action for reducing bycatch of sensitive species.

	decision to make), and provide an update on the HBDSEG proposal (UK Seal monitoring) mentioned in 2019?	We therefore require SCOS to help identify what the current gaps in scientific knowledge are for seal bycatch and how best to collect additional information to provide valuable evidence of the current issue in commercial fisheries.
5	**Seal Depredation in commercial fisheries:** Can SCOS advise on what information is available to provide evidence of seal depredation in the UK and any seasonal / geographical hot spots where this is known to be a prominent problem? Can SCOS also advise on how to further investigate and address this issue? To include an update on SMRU pursuing funds to explore this issue through information collected on seal-damaged fish recovered from nets (under bycatch monitoring scheme)?	We have seen increasing complaints from the fishing industry of seal depredation for large percentages of catch reported. There are now heightened animal welfare concerns around such interactions between fishers and seals and any intentional or reckless killing of seals by fishers, in light of recent Fisheries Bill amendments to remove the 'Netsman's Defence' and ability to apply for a licence to shoot seals.
6	**Seal Disturbance on beaches (animal welfare concern):** Can SCOS advise and provide seasonal and geographical mapping (within SoS waters) of current haul out sites where seal disturbance by members of the public is of most concern? Can SCOS advise and review latest scientific evidence on impact of seal disturbance and potential code of conduct measures that could be implemented to avoid seal disturbance by member of public on beaches? Are there best practice examples from other countries in terms of measures to control disturbance (e.g. Regulations, protected sites and/or codes of conduct). What would SCOS recommend in each of the devolved nations (given that Scotland have different legislation in place and have already designated nationally important haul out sites). Does SCOS believe that the Scottish system of designated sites helps reduce disturbance?	There has been increasing media attention on seal disturbance and seal 'selfies', which can cause seals to flush into the sea. This has an energetic cost for seals which can affect their overall health and could also cause mothers to abandon their pups. This issue has been further heightened by Covid-19 due to an increase in 'stay at home' UK tourism. We are receiving increasing complaints from seal charities that people are simply unaware of how to behave when watching or taking photos of seals and the negative impact they can cause. Defra are looking to work in collaboration with seal charities, scientific experts and MMO to initiate a public awareness social media campaign to help prevent seal disturbance on beaches. If scientific evidence of the negative impacts of disturbance on seals were found, it could feed into the management of MPAs and the creation of regional bylaws.

7	**Changes to seal legislation:** Given recent government amendments to the Conservation of Seals Act 1970 and the Wildlife (Northern Ireland) Order 1985, can SCOS review and advise as to whether there is any significant scientific requirement or advantage in making any further legislative amendments for seals in SOS waters? For example, do SCOS believe that the Scottish legislation and nationally important haul out sites better protects seals?	Following recent government amendments to the Conservation of Seals Act 1970 and the Wildlife (Northern Ireland) Order 1985, to address animal welfare issues whilst ensuring that UK fisheries exports are compliant with the US Marine Mammal Protection Act, Defra would like to determine whether any further improvements could be made in the future.
8	**Impacts on seals from plastic pollution:** Can SCOS review and provide an update on any new studies looking into how macroplastics, microplastics, abandoned (ghost) fishing gear and other plastic pollution are affecting seal populations? Is there a need for more research to be done on this subject area? Could such impacts be picked up in part under reporting of strandings and post-mortem work by CSIP?	Due to various microplastics and microplastics pollution having a significant negative effect on marine life, it would be important to also understand how plastic pollution has and is affecting seal populations. Exposure to neurotoxic PCBs have been shown to have a negative effect on other marine mammals: Reduced fertility in UK Orcas; harbour porpoise calves exposed to PCBs in mothers' milk. This could also be the case for UK seals that occupy a similar position in the food chain. High levels of PCBs found in porpoises under laws in some countries, could meet the criteria for being defined as toxic waste. Again, this could become a concern with UK seals. This may be considered too big / new a topic to bring in for full literature review at this stage but SCOS might recommend how best to tackle increasing understanding and monitoring within this area of work as will be an area of increasing importance going forwards which will require careful consideration at the policy level.
9	**Impacts on Seals through climate change:** Can SCOS review latest scientific information available on current environmental impacts seals face due to climate change, such as acidification, sea level changes and coastal collapses and changing prey distributions.	Due to climate change having a significant negative effect on marine life, it would be important to understand how climate change has and is affecting seal populations. This may be considered too big / new a topic to bring in for full literature review at this stage but SCOS might recommend how

		best to tackle increasing understanding and monitoring within this area of work as will be an area of increasing importance going forwards which will require careful consideration at the policy level.

SCOS Questions. NRW. October 2020. Dr Thomas Stringell

1. **Monitoring in Wales – ground counts**

In Wales, many grey seal pupping sites tend to occur in cryptic habitats such as sea caves and habitats that make detection of pups via aerial surveying problematic. However, many sites are also generally difficult to access during ground counts (by boat/foot/cliff top viewing) even for those that are open coast sites (ie boulder/pebble beaches). For these sites aerial or drone surveys would be advantageous. The proportion of cryptic sites varies around the coast but is approximately half of the pupping sites (eg see recent North Wales Monitoring Report, Clarke et al in prep). Monitoring open coast sites by air and applying a multiplier for cryptic sites (ie x 2) might be an option, with obvious caveats of uncertainty. Nevertheless, NRW and partners (eg RSPB) do conduct annual ground counts at some key locations around Wales (Skomer MCZ, Ramsey Island, Bardsey Island up until last year). Some of these datasets go back several decades.
What are the statistical reasons for not being able to incorporate these data into UK wide pup production models? Could/should the way in which data is collected here be changed to allow the data to be incorporated? And would aerial/drone surveys potentially be a way forward given the obvious issues of not being able to cover cryptic sites?

2. **Latest info on collision risk**

What is the latest information on collision risk for seals (especially grey seals) with tidal stream devices? Are there any updated data to inform the degree of avoidance?

3. **Current information on UK and regional population estimates**

What are the latest grey seal and common seal population and pup production estimates for UK and its regional Seas? We would be particularly interested to have pup production and population estimates for Wales, The Irish Sea, The Celtic Sea (SW approaches including SW England, Wales and South and SE Ireland), East coast Ireland, West coast Ireland, West Coast Scotland etc separately so that we can combine various spatial scenarios to inform management. This links to our question about appropriate scale for Management Units (see below). In particular, the spatial scales we are interested in are the pup production and population estimates associated with each of the relevant ICES Areas: a separate estimate for each of 7a, 7g and 7f, 7b, 7j, 7h, 7e and 6a, which will be combined variously to inform putative Management Units. These start with the smallest combination (7a, g and f), a medium sized combination (7a, g, f, j, h, e), a slight increase from the previous to also include7b, and at their largest all the previous Areas plus 6a, which is effectively Western British Isles - the OSPAR Region III area.

4. **Management Units**

The extent of the interconnectivity of the grey seal population in Celtic and Irish Seas and Irish Atlantic region is well evidenced (eg see previous SCOS reports/questions). However, the extent of movement and connection can be as large as the Western half of the British Isles (UK and Ireland) – the OSPAR III ecoregion - which represents a potential Management Unit (MU) area that has been used in environmental assessments for some significant developments around Wales. At the other extreme, the smallest Management Unit for grey seals is the SCOS MUs (ie Wales) which NRW consider to be too small for relevant use in environmental assessments (Environmental Impact Assessment [EIA], Habitats Regulations Assessment [HRA], Strategic Environmental Assessment [SEA] etc) as they stop artificially at the UK midline and jurisdictional boundaries. The spatial scale of MUs is important as it underpins our statutory advice for EIA and HRA (and other environmental assessments) and denotes the screening distances for sites (SACs) in HRA and projects (developments) to include in cumulative assessments (EIA) and in-combination assessments (HRA). MUs shouldn't stop at the mid-line (UK only) as this risks the lack of assessment at sites (SACs) that are known to have potential functional linkage in the region due to the high degree of population connectivity between Wales, Ireland, SW England and France. An early proposal for a grey seal MU by the Interagency Marine Mammal Working Group (IAMMWG) in 2013 was the South and West England and Wales MU, but this also stopped artificially at the UK mid- and southern- line and NRW

do not consider this to be appropriate. Presently, the IAMMWG do not have an agreed/published MU for grey seals or harbour seals in the Celtic and Irish Seas, unlike for cetaceans as described in IAMMWG (2015)[17].
As a pragmatic solution to the lack of agreed MU for grey seal (and potentially common seal) in the region, NRW would like SCOS to calculate the pup production and population estimates for grey seal (and common seal[18]) and explore the validity of the science supporting four putative MU spatial scales:

1. ICES Areas 7a, 7g and 7f - Celtic Approaches and Irish Sea
2. ICES Areas 7a, 7g, 7f, 7j, 7h, and 7e – Celtic and Irish Seas
3. ICES Areas 7a, 7g, 7f, 7j, 7h, 7e, and 7b – Celtic and Irish Seas and West Ireland
4. ICES Areas 7a, 7g, 7f, 7j, 7h, 7e, 7b and 6b – Western British Isles or OSPAR Region III

5. PBR and bycatch

NRW uses PBR for assessing thresholds of 'allowable' marine mammal take for anthropogenic removals associated with marine developments, such as potential collisions with tidal stream devices. The PBR is used by NRW to inform Habitats Regulations Assessments and decisions on Adverse Effect on Site Integrity. At present the spatial scale we use is the population of Ireland, SW England and Wales as described in SCOS (2018) - pup production of 4100. We take a multiplier of 2.3 to give an Nmin of 9430. This gives a PBR of 283 (with Recovery Factor of 0.5). Bycatch in that same area far exceeds this, implying there is no headroom for further removals.
Does the spatial scale of this area adequately represent the appropriate scale for the population (see question 1)? From the answers to the MU question above, the pup production estimates in the 4 proposed variants of MUs can be utilised to calculate Nmin and PBR. But what are the latest bycatch estimates for grey seals (and harbour seals) in these same areas (Ireland, SW England and Wales area from SCOS 2018, and the four putative MU areas based on combinations of ICES areas)?
NRW consider the relevant grey seal Recovery Factor (F_R) for use in this application of PBR is 0.5, given we are concerned with SACs here. However, PBR calculations in Scotland appear to use an F_R of 1.0. What would SCOS recommend the F_R should be for the particular use we are considering here (ie HRA) and why?
Despite this PBR and bycatch, populations in the region (pups) are increasing suggesting the PBR is not correct for several reasons. What is SCOS' explanation for this disparity?
Given that there is uncertainty in the use of PBR for this purpose (due to the disparity outlined above ie uncertainties in input parameters, spatial scale etc), what alternative approaches do SCOS suggest might be plausible for determining how many removals (mortalities), eg from collisions with tidal developments, in the region (alone or in combination with other plans and projects and activities/pressures) is too many?

6. SAC condition indicators

NRW are currently undergoing a review of indicators to determine condition of SACs features – grey seal. A usual indicator of feature condition is pup production with a target of a stable or increasing pup production in the SAC. Other indicators are typically things like quality of supporting habitat (habitat is accessible, suitable pupping/moulting/resting sites are available), distribution of pupping sites in SAC (and that they are maintained or increasing) (for example see UK Common Standards Monitoring[19]). What other indicators might reliably provide a measure of condition? Can any population structure/dynamic indicators be useful, such as degree of site fidelity, age structure, fecundity (crude birth rates), pup survival, mortality etc? Can any of these population dynamic

[17] IAMMWG (2015). Management Units for cetaceans in UK waters (January 2015). JNCC Report No. 547, JNCC Peterborough. Available at: https://hub.jncc.gov.uk/assets/f07fe770-e9a3-418d-af2c-44002a3f2872
[18] Wales does not have and SACs with harbour seal as a feature but developments in Wales may affect harbour seal sites elsewhere
[19] https://hub.jncc.gov.uk/assets/58eb48d9-2523-4397-93df-77e21a8ac51d

factors be reliably measured? We suppose that some of these factors are potentially similar to those used in the UK pup production model, but are these useful at a smaller (eg site-based, regional) scale?

And given that sites (SAC conservation objectives) in Wales are not only about pups, what other population measures might be useful to indicate how well the condition of the SAC and the population is doing?

ANNEX III Briefing Papers for SCOS

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

List of briefing papers

Estimating the size of the UK grey seal population between 1984 and 2019.

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Abstract

We fitted a Bayesian state-space model of British grey seal population dynamics to two sources of data: (1) regional estimates of pup production from 1984-2016 and 2018 North Sea region, and (2) independent estimates assumed to be of total population size just before the breeding season in 2008 and 2014. The model allowed for density dependence in pup survival, using a flexible form for the density dependence function, and assumed no movement of recruiting females between regions. This model is identical to that used to provide last year's advice; the data used in the main run are nearly identical (pup production estimates differ slightly from last year) except for the addition of the 2018 estimate for North Sea region.

Estimated population size in regularly monitored colonies in 2019 was 133,900 (95% CI 115,300-156,500). The population overall is estimated to be increasing at a rate of 1.4% per year.

In a supplementary run, we used an alternative set of pup production estimates derived by making a different assumption about the probability of correctly classifying moulted pups from aerial digital images. The estimate of total population size was almost identical. However, a previous analyses has shown that assumptions made in the pup production model can affect estimates of total population size, so the result obtained here should not be generalized.

Female fecundity is assumed constant in the population model but in reality may be affected by environmental conditions during the previous year. We undertook an exploratory analysis of the relationship between fluctuations in estimated pup production around the modelled trend and an index of North Atlantic Oscillation. No strong relationship was found.

Introduction

This paper presents estimates of British grey seal population size and related demographic parameters, obtained using a Bayesian state-space model of population dynamics fitted to pup production estimates (from aerial surveys of breeding colonies) and independent estimates of total population size (from haul-out counts). The model and fitting methods are the same as those employed in recent years and are described in detail in Thomas et al. (2019). The data are nearly identical (see Methods) to those used in the analysis presented last year (Thomas 2019): pup production estimates for 1984-2016, plus independent estimates of total population size from 2008 and 2014; the one major addition is an estimate of pup production for the North Sea region from 2018. The prior distributions on model parameters are the same as those used last year.

We present estimates of population size at the start of the 2019 breeding system (i.e., projected forward one year from the last data point in North Sea and three years for the other regions). Note that all estimates of population size relate to seals associated with the regularly monitored colonies. A multiplier is required to account for the ~10% of seals that breed outside these colonies.

The pup production estimation method is currently undergoing a revision, and one aspect of estimation that is being examined is the probability of correctly classifying a moulted pup from the film and digital aerial survey images ("PMoult"[20]). In the main run, the pup production estimates are based on a PMoult of 0.5 for film and 0.9 for digital images. The change to 0.9 was based on the increased quality of the digital images, compared to the film; this is the value used in previous briefing papers. However, work presented at the SCOS meeting in 2019 suggested that the improvement in correct classification with digital images is substantially less, and so a value less than 0.9 was warranted. To provide a sensitivity analysis, we present results from a supplementary run of the population model using pup production estimates of 0.5 for both film and digital images.

Female fecundity is assumed constant in the population model but, in reality, it is likely to be at least partly subject to environmental factors regulating females' ability to gain fat reserves before breeding. One potential seasonal indicator is the North Atlantic Oscillation (NAO). We undertake a preliminary investigation of the relationship between fluctuations in pup production around the modelled trend and an NAO index from the previous winter, and also lagged by a further year.

Methods

Main run

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

Input data was pup production estimates for 1984-2016 and the North Sea region estimate for 2018. The estimates for 1984-2016 are nearly identical to those used in last year's briefing paper (Thomas 2019), which were reported in Duck and Morris (2018), but there are some minor differences as shown in Appendix Figure A1. One difference is that we no longer use a pup production estimate for Inner Hebrides in 2009 – in that year poor weather prevented enough flights to obtain a reliable estimate, and in previous briefing papers we have used the figure for 2008. This year it is recorded as a missing value. A second difference is that the PMoult value used in pup production estimation for 2008-2010 was set at 0.5 for 2008-2010, while in previous briefing papers this was treated differently (estimated, in most cases) in the pup production model. Russell et al. (2019) used a fixed value of 0.5 and Thomas (2018) examined the effect of this change on population estimation (Additional analysis 2),finding it to be small (3% lower). The third difference was some small updates to numbers from ground-counted colonies.

[20] To be precise, this parameter is the probability of correctly classifying a light-coated pup as a moulted pup; the pup production model contains an assumption about the proportion of moulted pups that are dark-coated.

The other source of data is the independent estimates of total population size from 2008 and 2014, which are the same as those used in last year's briefing paper and come from Russell et al. (2016).

Model fitting, as in previous reports, used a stochastic simulation-based procedure called a particle filter (Thomas et al. 2019). Reliability of reported results depends on the number of simulations. Here, 2 billion simulations were used, which gave results accurate to 2-3 significant figures.

Supplementary run

As described earlier, one important parameter in pup production estimation is the probability of correctly classifying moulted pups from the images, PMoult (Russell et al. 2019). This probability has been set at 0.9 for the digital images collected since 2012. As part of an ongoing review of pup production estimation, it was desired to assess the effect of setting PMoult for digital images to 0.5. This results in lower pup production estimates for the digital survey years (post 2010) (Appendix Figure A1), except in the North Sea region where the majority of pup production estimates are derived from ground counts. A supplementary run of the population model was performed with these alternative pup production estimates.

NAO and pup production

We calculated standardized pup production residuals by subtracting the posterior mean pup production for the corresponding region and year from the pup production estimates and dividing by the standard deviation of pup production estimates for that region. We regressed these residuals on an index of NAO for the winter before the breeding season (using ordinary linear regression). The NAO index used was the station-based December-March index of Hurrell (2020). Because there may be a lag in environmental conditions changing and corresponding changes in food resources we also regressed standardized pup production on the 1-year lagged NAO.

Results

Main run

Estimated pup production by region from the model matches the observed values reasonably well although it is clear that the pup production estimates for Inner and Outer Hebrides and Orkney are substantially higher after the advent of digital surveys in 2012 and that this affects the fit: residuals for several years before this are all negative and after are all positive (Figure 1). In the case of Inner and Outer Hebrides, the post-2012 estimates are considerably higher than predicted. A similar tendency is seen in North Sea, but to a much lesser extent. Overall, pup production is estimated to be increasing strongly in North Sea, have stabilized in the decade after 1995 in Inner and Outer Hebrides, and have recently stabilized in Orkney (Figure 1).

Total population size is estimated to have grown steadily, although at a slightly decreasing rate; population size is estimated to have been larger than the independent estimate from 2008 and smaller than that from 2014 (Figure 2). Posterior mean population size in regularly monitored colonies in 2019 was 133,900 with 95% credible interval (CI) 115,300-156,500. Estimates by region are given in Table 2 and estimates for all years 1984-2019 are given in the Appendix Table A1. The estimated growth in population size between 2018 and 2019 is 1.4%.

Posterior parameter distributions are shown in Figure 3, with numerical summaries in Table 1. The estimates are generally very similar to those reported by Thomas (2019), although adult survival is estimated to be slightly lower and pup survival higher (the two are strongly negatively correlated, Thomas 2019); the density dependent shape parameter is somewhat higher and carrying capacity lower. Three regions (Inner Hebrides, Outer Hebrides and Orkney) are estimated to be close to or slightly over carrying capacity (i.e., posterior mean on carrying capacity parameter at or close to the pup production), while North Sea is at approximately 60% of carrying capacity (although that estimate is quite imprecise with SE/mean=0.3). Estimated sex ratio is, as previously, unchanged from the prior.

Supplementary run

Despite lower pup production estimates in Inner and Outer Hebrides and Orkney going into the model, the resulting estimates of total population size were almost identical (Table 2, last column). While carrying capacity was estimated to be lower in the three regions for which pup production was lower, it was estimated to be higher in North Sea (Table 1, last column), and the two appear to have balanced out in terms of total population size.

NAO and pup production

There was no apparent relationship between the temporal pattern of standardized pup production residual at either regional or overall level and NAO index (Figure 4). The linear least squares regression slopes were positive in almost all cases but were not statistically significant for either NAO or lagged NAO; the coefficient of determinations (i.e., proportion of variation explained by the regression) was low in all cases (Figures 5 and 6).

Discussion

Estimated population size in the main run is slightly smaller than that reported in last year's briefing paper (Thomas 2019) for comparable years – for example the total population size estimate in 2018 from Thomas (2019) was 137,200 (95% CI 121,000-156,100) while here the estimate for the same year is 4% smaller at 132,100 (95% Ci 115,000-153,600). We conclude that the small changes in pup production estimates, plus the addition of the extra year of data for North Sea have had a small effect on the parameter estimates and therefore population trajectory. This finding is in line with that of the additional analysis undertaken by Thomas (2018). The slightly lower carrying capacities and fecundity lead to slightly lower estimates of pup production and total population size respectively.

By contrast, the changes in pup production estimates from digital aerial images (post 2010) in the supplementary run had almost no effect on the resulting estimate of total population size. It appears that changes in pup production estimates can sometimes influence total population size, but other times have very little inference. An investigation of pup production estimation methods is ongoing; in the meantime we suggest treating the estimates reported here with appropriate caution. Currently the two additional estimates of total population size, from 2008 and 2014, are assumed to be statistically independent. Although they are based on separate aerial surveys of hauled-out seals, in scaling up from counts of seals hauled out to total population size both rely on the same estimate of the proportion of seals hauled out. Future work will account for this in the population estimation methods used here; we anticipate the effect will be to increase the estimated population size. This is because estimates from the population model and pup count data alone are higher than those from the independent estimate (Thomas 2018), and the effect of accounting for the dependence will be to increase the influence of these estimates. A third independent estimate is also due to be produced in the near future.

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

Our initial look for an association between NAO and variation in pup production yielded no pattern. It may be that there is none to be found – after all, NAO changes are likely far removed from possible changes in seal prey and hence seal fecundity. On the other hand, the current recent estimates of pup production are under review. We will therefore return to an investigation of possible drivers of variation in fecundity once revised estiamtes of pup production are available.

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Table 1. Prior parameter distributions and summary of posterior distributions. Be denotes beta distribution, Ga Gamma distribution (with parameters shape and scale, respectively). Analysis uses 1984-2016 and 2018 (North Sea only) pup production estimates, and the 2008 and 2014 total population estimates. Posterior estimates are shown for two runs: a main run, assuming probability of correct classification of moulted pups from digital aerial images is 0.9, and a supplementary run when where this probability is assumed to be 0.5.

Parameter	Prior distribution	Prior mean (SD)	Posterior mean (SD)	
			Main run	Suppl. run
adult survival ϕ_a	0.8+0.17*Be(1.79,1.53)	0.90 (0.04)	0.96 (0.01)	0.96 (0.02)
pup survival ϕ_{pmax}	Be(2.87,1.78)	0.62 (0.20)	0.46 (0.09)	0.49 (0.09)
Fecundity α	0.6+0.4*Be(2,1.5)	0.83 (0.09)	0.90 (0.06)	0.91 (0.06)
dens. dep. ρ	Ga(4,2.5)	10 (5)	4.3 (1.1)	4.5 (1.4)
NS carrying cap. χ_1	Ga(4,5000)	20000 (10000)	24300 (7830)	27000 (9170)
IH carrying cap. χ_2	Ga(4,1250)	5000 (2500)	3480 (289)	3340 (216)
OH carrying cap. χ_3	Ga(4,3750)	15000 (7500)	12500 (780)	12100 (604)
Ork carrying cap. χ_4	Ga(4,10000)	40000 (20000)	21200 (2960)	20300 (2560)
observation prec. ψ	Ga(2.1,66.67)	140 (96.6)	72.2 (19.7)	83.9 (21.2)
sex ratio ω	1.6+Ga(28.08, 3.70E-3)	1.7 (0.02)	1.7 (0.02)	1.7 (0.02)

Table 2. Estimated size, in thousands, of the British grey seal population at the start of the 2019 breeding season, derived from a model fit to pup production data from 1984-2016 and 2018 (North Sea only), and the additional total population estimates from 2008 and 2014. Estimates from two runs are shown: a main run, assuming probability of correct classification of moulted pups from digital aerial images is 0.9, and a supplementary run when where this probability is assumed to be 0.5. Values in the table are posterior means with 95% credible intervals in brackets.

	Estimated population size in thousands (95% CI)	
	Main run	Supplementary run
North Sea	46.5 (35.8 61.6)	49.4 (37.1 61.8)
Inner Hebrides	8.2 (6.9 10.1)	8 (6.7 9.6)
Outer Hebrides	29.6 (25 34.8)	28.9 (25 35.4)
Orkney	49.6 (40.7 62.8)	47.7 (39.2 57.6)
Total	133.9 (115.3 156.5)	133.9 (116.4 155.3)

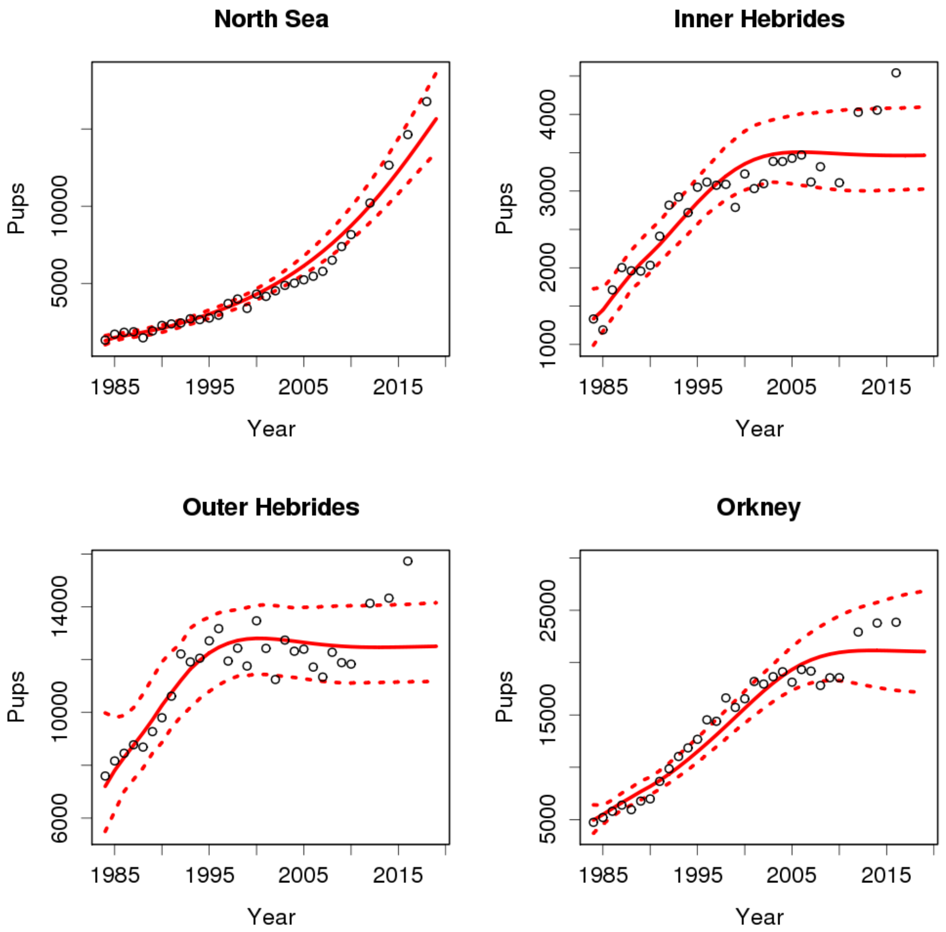

Figure 1. Posterior mean estimates of pup production (solid lines) and 95%CI (dashed lines) from the model of grey seal population dynamics, fitted to pup production estimates from 1984-2016 and 2018 (North Sea only) (circles) and the total population estimates from 2008 and 2014.

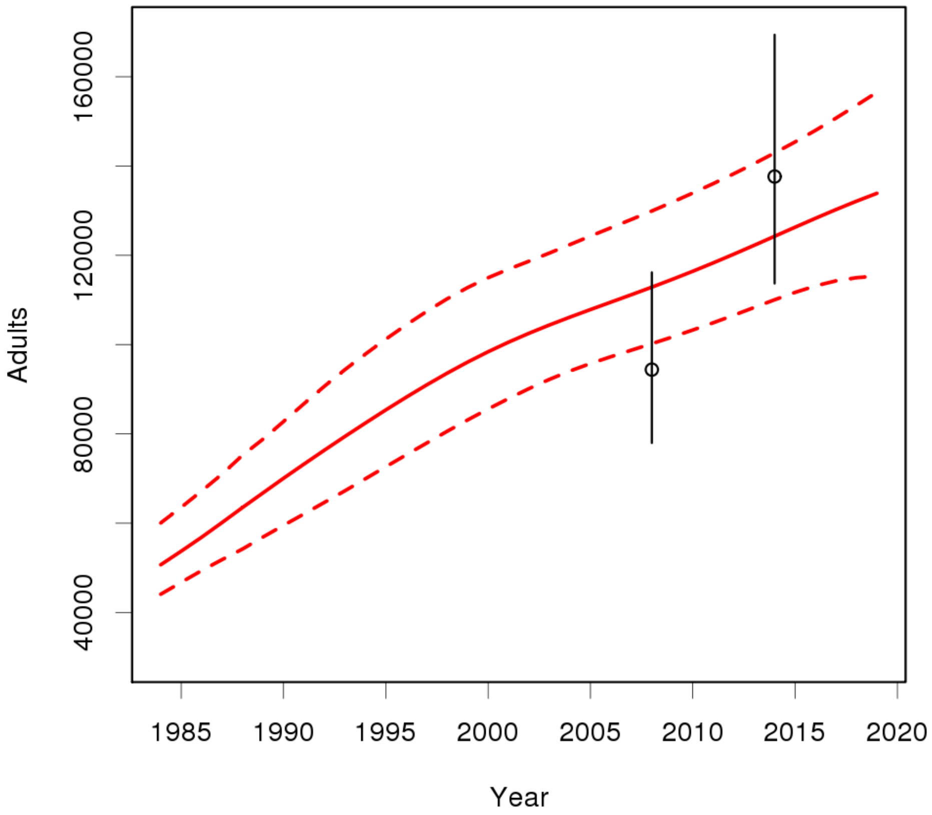

Figure 2. Posterior mean estimates (solid lines) and 95%CI (dashed lines) of total population size in 1984-2019 from the model of grey seal population dynamics, fit to pup production estimates from 1984-2016 and 2018 (North Sea only), and total population estimates from 2008 and 2014 (circles, with vertical lines indicating 95% confidence interval on the estimates).

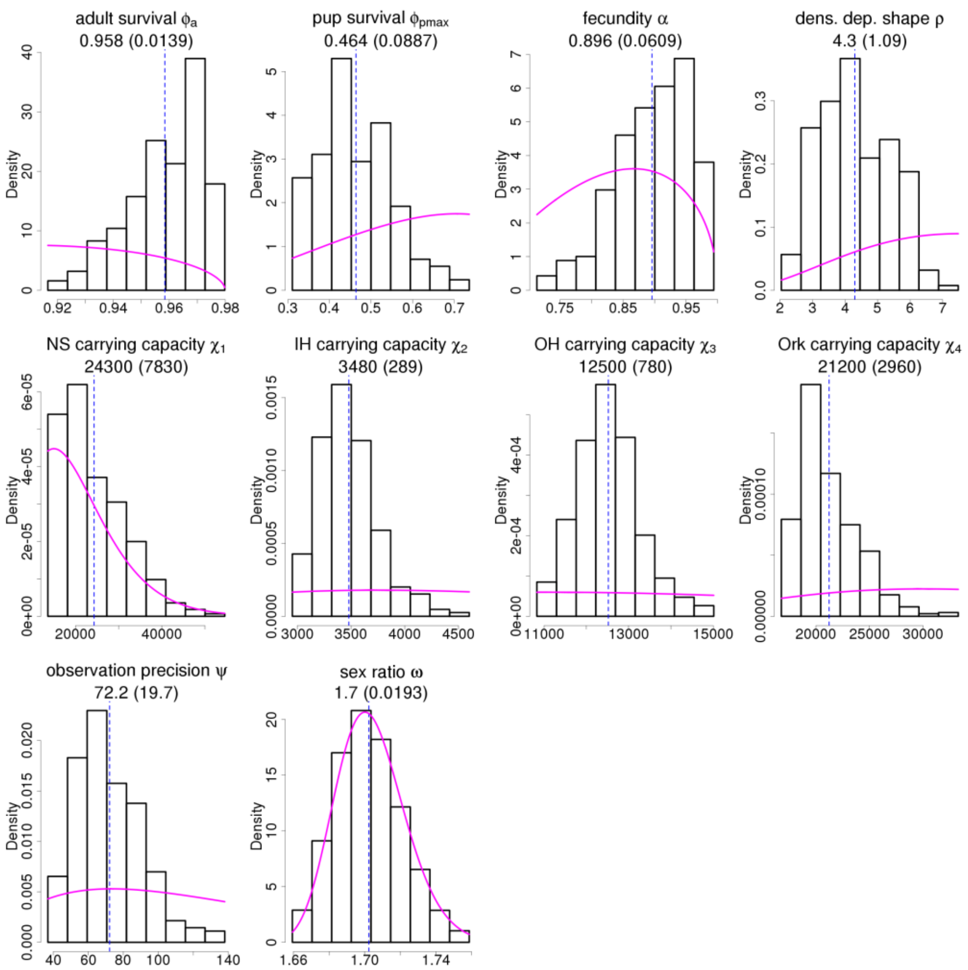

Figure 3. Posterior parameter distributions (histograms) and priors (solid lines) for the model of grey seal population dynamics, fit to pup production estimates from 1984-2016 and 2018 (North Sea only), and total populations estimate from 2008 and 2014. The vertical dashed line shows the posterior mean; its value is given in the title of each plot after the parameter name, with the associated standard error in parentheses.

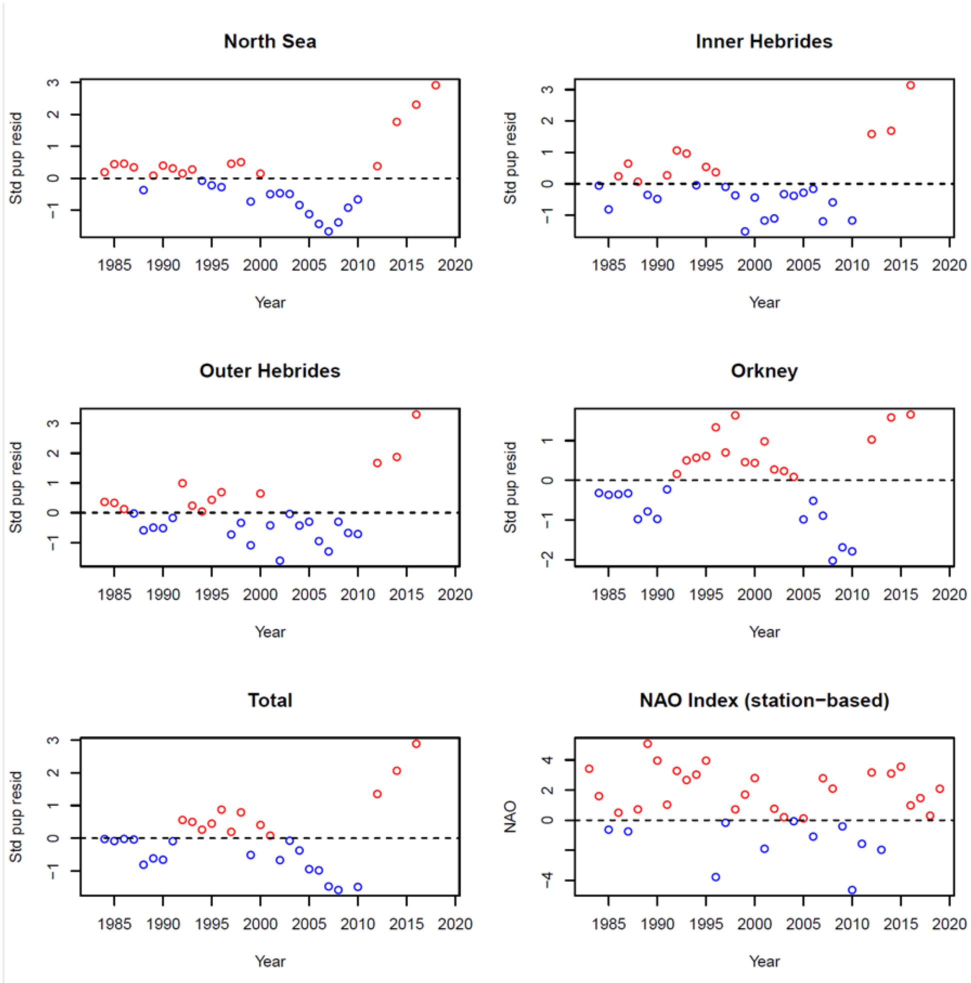

Figure 4. Standardized residuals of pup production at regional and total level (first 5 panels) and NAO index (bottom right panel) over time. In all cases zero is indicated with a dashed line; positive values are shown in red and negative ones in blue.

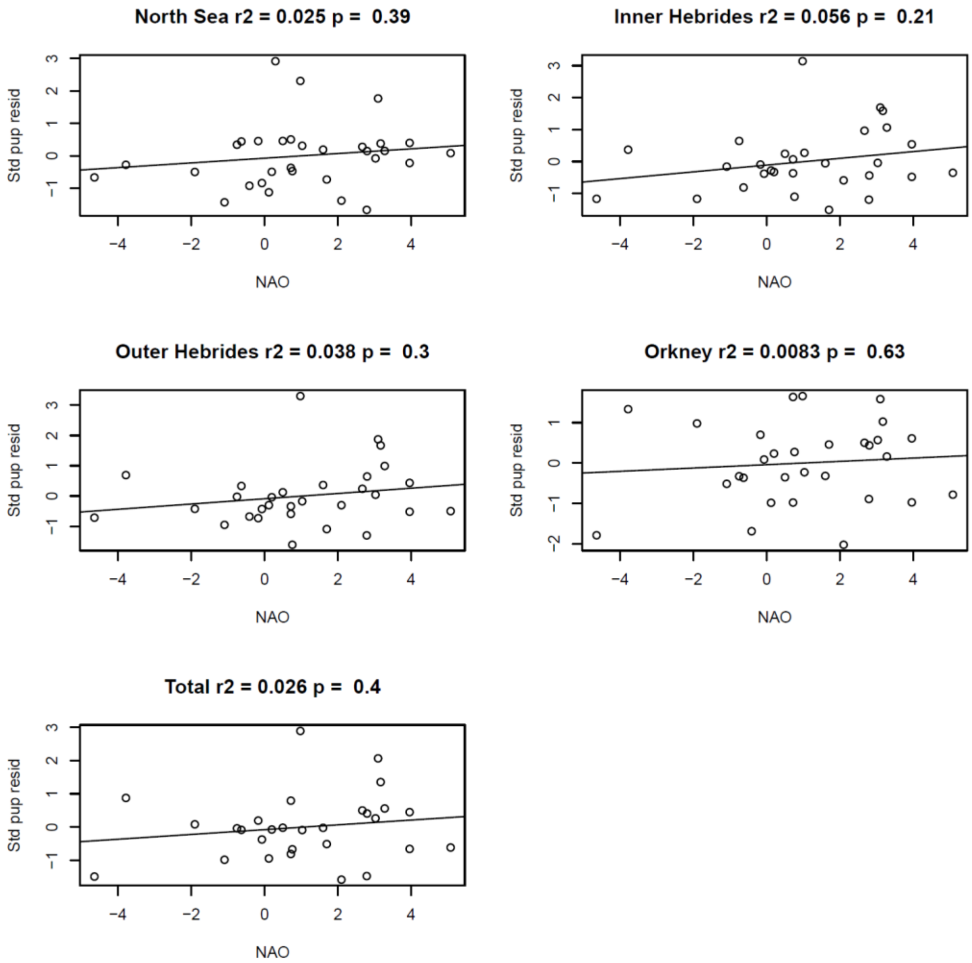

Figure 5. Standardized residuals of pup production at regional and total level plotted against the corresponding NAO index value for the previous winter. The linear least squares regression fit is shown as a solid line. The coefficient of determination (r^2) from the regression is shown in the plot title, together with the *p*-value from a *t*-test of the null hypothesis that the regression slope is zero.

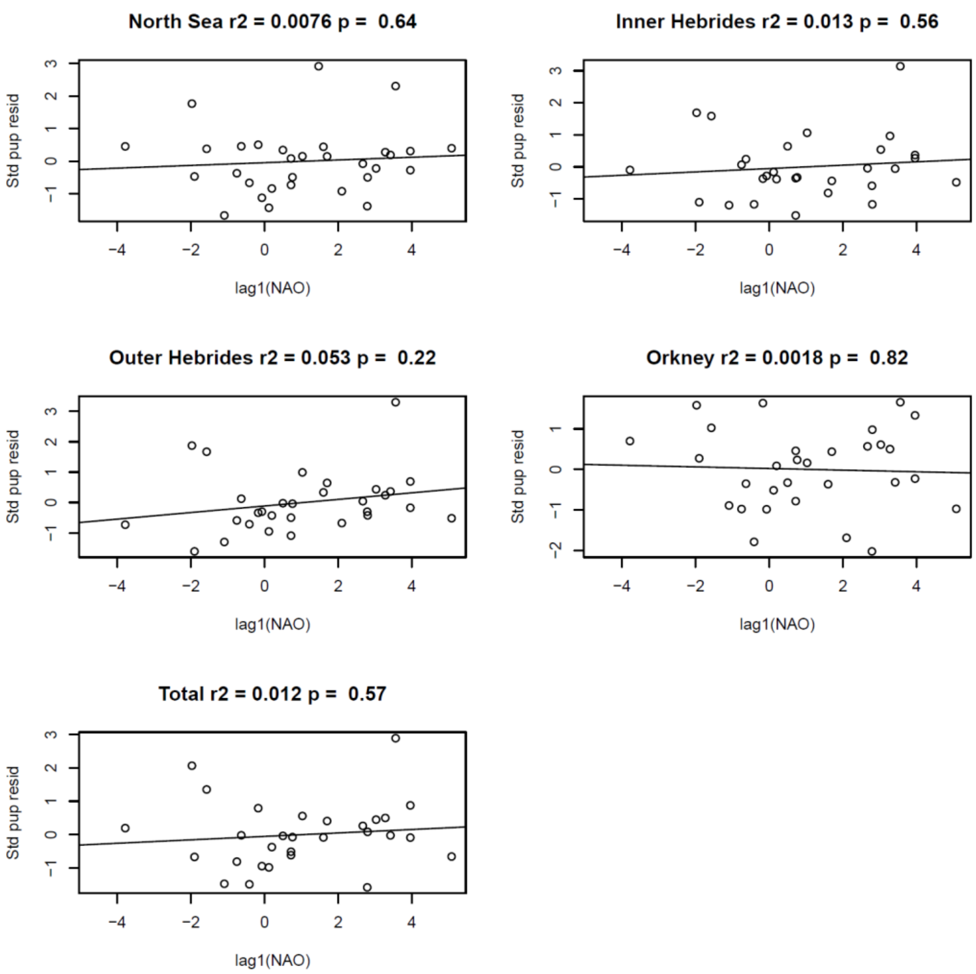

Figure 6. Standardized residuals of pup production at regional and total level plotted against the corresponding NAO index value for winter before the previous one (i.e., a lag of one year). The linear least squares regression fit is shown as a solid line. The coefficient of determination (r^2) from the regression is shown in the plot title, together with the *p*-value from a *t*-test of the null hypothesis that the regression slope is zero.

Appendix

Table A1. Estimates of total population size, in thousands, at the beginning of each breeding season from 1984-2019, made using the model of British grey seal population dynamics fit to pup production estimates from 1984-2016 and 2018 (North Sea only), and total population estimates from 2008 and 2014. Numbers are posterior means followed by 95% credible intervals in brackets.

Year	North Sea	Inner Hebrides	Outer Hebrides	Orkney	Total
1984	4.6 (3.9 5.5)	4.9 (4 6)	23 (19.2 28.5)	18.2 (15.2 22.3)	50.7 (44.1 60.1)
1985	4.9 (4.2 5.9)	5.2 (4.2 6.3)	24.3 (20.2 30)	19.3 (16.1 23.6)	53.7 (46.7 63.6)
1986	5.3 (4.6 6.3)	5.5 (4.5 6.7)	25.4 (21.3 31.3)	20.7 (17.3 25.1)	56.9 (49.4 67.2)
1987	5.7 (5 6.8)	5.8 (4.8 7.1)	26.5 (22.2 32.5)	22.1 (18.5 26.7)	60.1 (51.8 71)
1988	6.2 (5.4 7.3)	6.1 (5 7.5)	27.5 (22.8 33.8)	23.7 (19.8 28.6)	63.5 (54.2 75.2)
1989	6.6 (5.8 7.8)	6.4 (5.2 7.9)	28.3 (23.4 34.6)	25.4 (21.2 30.7)	66.8 (56.9 78.8)
1990	7.1 (6.2 8.4)	6.8 (5.5 8.3)	29 (23.9 35.2)	27.2 (22.7 32.9)	70 (59.5 82.8)
1991	7.6 (6.7 9)	7 (5.7 8.6)	29.5 (24.3 35.5)	29 (24.2 35.1)	73.2 (62.1 86.8)
1992	8.2 (7.2 9.6)	7.3 (6 9)	29.9 (24.5 35.6)	31 (25.7 37.5)	76.4 (64.7 90.7)
1993	8.8 (7.7 10.3)	7.6 (6.2 9.3)	30.1 (24.7 35.7)	32.9 (27.3 39.9)	79.4 (67.2 94.4)
1994	9.5 (8.3 11.1)	7.8 (6.3 9.5)	30.2 (24.9 35.9)	35 (29 42.4)	82.4 (69.9 97.9)
1995	10.2 (8.9 11.9)	7.9 (6.5 9.8)	30.3 (25 36.2)	37 (30.7 44.9)	85.4 (72.6 101.2)
1996	10.9 (9.5 12.8)	8.1 (6.6 9.9)	30.3 (25.2 36.2)	39 (32.4 47.4)	88.2 (75.3 104.4)
1997	11.7 (10.2 13.7)	8.2 (6.7 10)	30.2 (25.2 36)	40.9 (34.1 49.6)	91 (77.9 107.4)
1998	12.6 (11 14.7)	8.2 (6.7 10.1)	30.1 (25.2 35.8)	42.7 (35.8 51.4)	93.6 (80.6 110.3)
1999	13.5 (11.7 15.8)	8.3 (6.8 10.2)	30 (25.2 35.6)	44.3 (37.4 53)	96.1 (83.1 112.8)
2000	14.5 (12.6 17)	8.3 (6.9 10.2)	29.9 (25.2 35.4)	45.7 (38.8 54.6)	98.4 (85.6 115)
2001	15.6 (13.5 18.2)	8.3 (6.9 10.3)	29.8 (25.1 35.3)	46.9 (39.9 56.1)	100.5 (87.9 116.9)
2002	16.7 (14.4 19.6)	8.3 (6.9 10.2)	29.7 (25.1 35.2)	47.9 (40.7 57.2)	102.5 (90.1 118.7)
2003	17.9 (15.4 21)	8.3 (6.9 10.2)	29.6 (25.1 35.1)	48.6 (41.3 58.1)	104.4 (92.2 120.5)
2004	19.2 (16.5 22.5)	8.3 (7 10.2)	29.5 (25.1 35)	49.1 (41.7 58.8)	106.2 (94.1 122.4)
2005	20.6 (17.6 24.2)	8.2 (7 10.2)	29.5 (25 34.9)	49.5 (41.9 59.3)	107.8 (95.8 124.3)
2006	22.1 (18.8 25.9)	8.2 (6.9 10.2)	29.5 (25 34.8)	49.7 (42 59.7)	109.5 (97.3 126.2)
2007	23.7 (20.1 27.8)	8.2 (6.9 10.1)	29.4 (25 34.7)	49.8 (41.9 60)	111.2 (98.7 128)
2008	25.4 (21.4 29.8)	8.2 (6.9 10.1)	29.4 (25 34.7)	49.9 (41.8 60.2)	112.9 (100.2 129.9)
2009	27.1 (22.9 31.9)	8.2 (6.9 10.1)	29.4 (25 34.6)	49.8 (41.7 60.5)	114.6 (101.7 131.9)
2010	29 (24.3 34.3)	8.2 (6.9 10.1)	29.5 (25 34.6)	49.8 (41.5 60.7)	116.4 (103.3 133.9)
2011	30.9 (25.9 36.7)	8.2 (6.9 10.1)	29.5 (25 34.7)	49.7 (41.4 61)	118.3 (104.9 136.1)
2012	32.9 (27.5 39.4)	8.2 (6.9 10.1)	29.5 (25 34.7)	49.7 (41.2 61.2)	120.2 (106.6 138.3)
2013	34.9 (29 42.1)	8.2 (6.9 10.1)	29.5 (25 34.7)	49.6 (41.1 61.5)	122.2 (108.3 140.5)
2014	37 (30.5 45)	8.2 (6.9 10.1)	29.5 (25 34.7)	49.6 (40.9 61.7)	124.3 (110 142.9)
2015	39 (31.9 48.1)	8.2 (6.9 10.1)	29.6 (25 34.8)	49.5 (40.9 62)	126.3 (111.7 145.4)
2016	41 (33.1 51.4)	8.2 (6.9 10.1)	29.6 (25 34.8)	49.5 (40.8 62.3)	128.3 (113.2 148)
2017	42.9 (34.3 54.7)	8.2 (6.9 10.1)	29.6 (25 34.8)	49.5 (40.7 62.5)	130.2 (114.3 150.7)
2018	44.8 (35.2 58.2)	8.2 (6.9 10.1)	29.6 (25 34.8)	49.5 (40.7 62.7)	132.1 (115 153.6)
2019	46.5 (35.8 61.6)	8.2 (6.9 10.1)	29.6 (25 34.8)	49.6 (40.7 62.8)	133.9 (115.3 156.5)

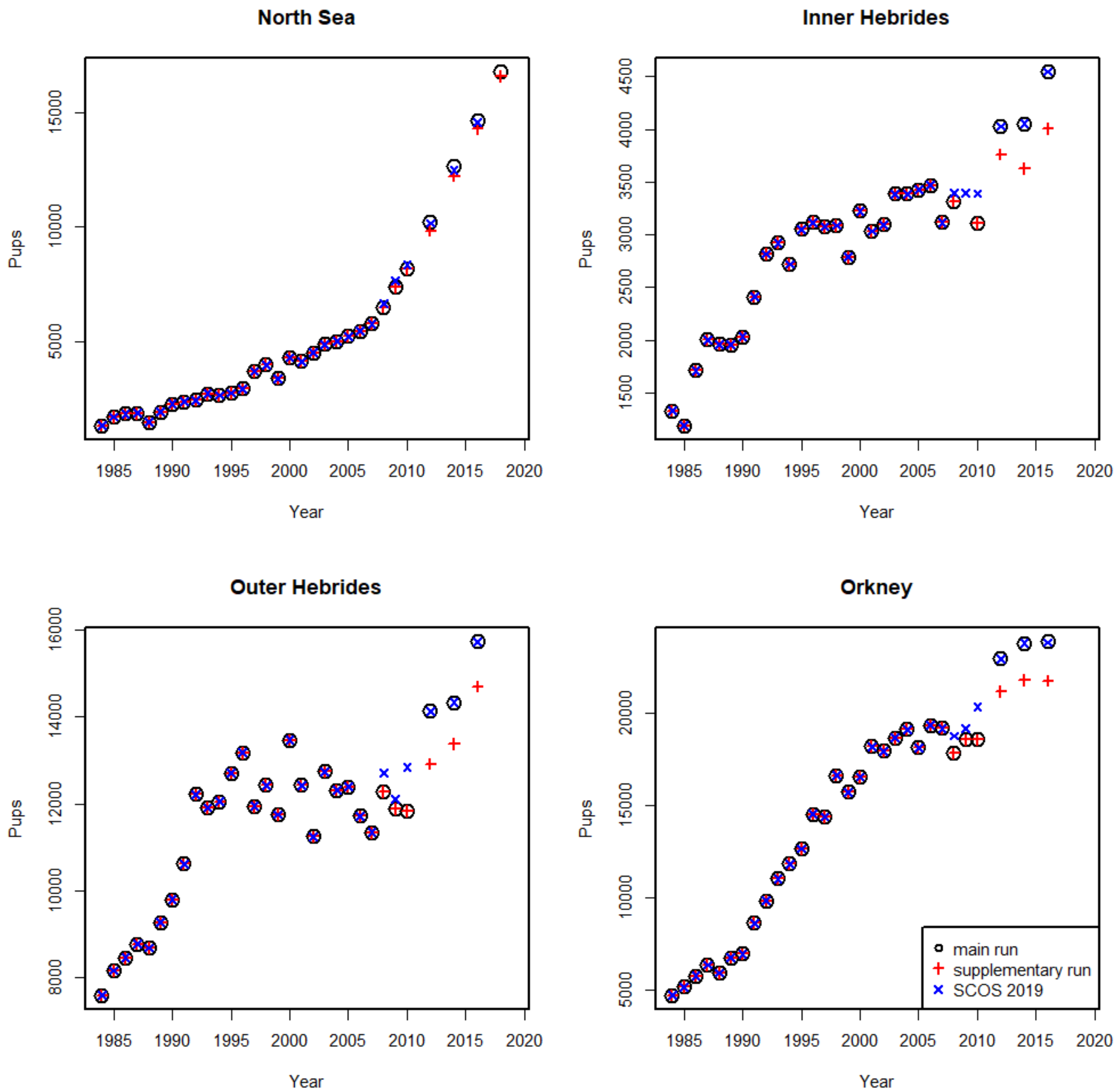

Figure A1. Comparison of pup production estimates used in the main run of this briefing paper (black circles), the supplementary analysis where probability of correct classification of moulted pups from aerial digital images was assumed to be 0.9 (red pluses) and last year's briefing paper (Thomas 2019) (blue crosses).

Annual review of priors for grey seal population model 2020

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Summary
Prior distributions (Table 1) for the grey seal population model (Thomas 2020) are required for the following model parameters: adult female survival ϕ_a, maximum pup survival $\phi_{p\max}$, fecundity α, shape of density dependence acting on pup survival ρ, region-specific carrying capacity (in terms of pup production) χ_{1-4}, number of adults per female ω, and precision of the pup production estimates ψ. The data used to inform these priors are presented below and in Tables 2 and 3. The resulting prior distributions are shown in Figure 1 and Table 1. These distributions are identical to those used in the previous year's analysis (Thomas 2020). Further discussion of previous and current prior selection is given in Lonergan (2012; 2014), and Russell (2017). Recent data, and any implications for the current priors, are highlighted. For study sites for which there are multiple estimates for a parameter, only the most comprehensive study is presented. This briefing paper is based on Supporting Information in Thomas et al. (2019).

Table 1. Prior parameter distributions input in Thomas (2020). Be and Ga denote beta and gamma distributions, respectively. Carrying capacity subscripts 1 to 4 refer to North Sea, Inner Hebrides, Outer Hebrides and Orkney regions.

Parameter	Prior distribution	Prior mean (SD)
adult survival $\boldsymbol{\phi_a}$	0.8+0.18*Be(1.79,1.53)	0.90 (0.04)
pup survival $\boldsymbol{\phi_{p\max}}$	Be(2.87,1.78)	0.62 (0.20)
fecundity $\boldsymbol{\alpha}$	0.6+0.4*Be(2,1.5)	0.83 (0.09)
dens. dep. shape $\boldsymbol{\rho}$	Ga(4,2.5)	10 (5)
carrying capacity $\boldsymbol{\chi_1}$	Ga(4,5000)	20000 (10000)
carrying capacity $\boldsymbol{\chi_2}$	Ga(4,1250)	5000 (2500)
carrying capacity $\boldsymbol{\chi_3}$	Ga(4,3750)	15000 (7500)
carrying capacity $\boldsymbol{\chi_4}$	Ga(4,10000)	40000 (20000)
observation precision $\boldsymbol{\psi}$	Ga(2.1,66.67)	140 (96.61)
sex ratio $\boldsymbol{\omega}$	1.6+Ga(28.08, 3.70E-3)	1.7 (0.02)

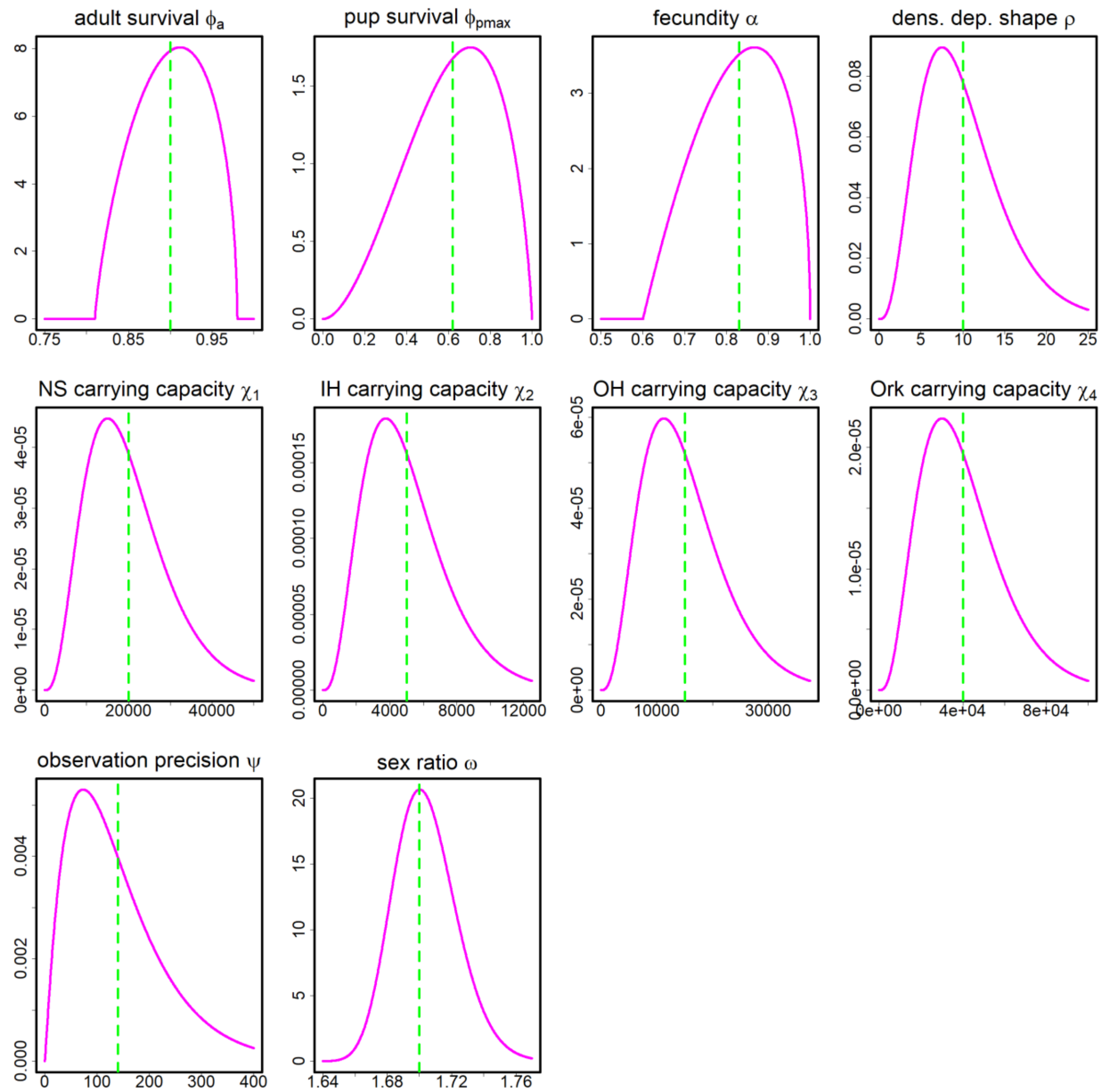

Figure 1. Prior probability density functions for each model parameter input in Thomas (2020), drawn from the distributions specified in Table 1. Carrying capacity subscripts 1 to 4 refer to North Sea, Inner Hebrides, Outer Hebrides and Orkney regions, respectively. Prior means are shown as green dashed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

Parameters

Adult female survival ϕ_a

Relevant studies are summarized in Table 2. Estimates of annual adult survival in the UK, obtained by aging teeth from shot animals are between 0.935 and 0.96 (Harwood & Prime, 1978; Hewer, 1964; Lonergan, 2012). Capture-mark-recapture (CMR) of adult females on breeding colonies can be used to estimate female survival but may produce underestimates as they are dependent on the assumption that females not returning to the study colony have died. Using capture-mark-recapture (CMR), adult survival was estimated to be between 0.87 and 0.95 (Smout, King & Pomeroy, 2019; see Table 2 for more details). Based on the above data, and the fact that the lower limit on adult survival cannot be lower than 0.8 (Lonergan, 2012), the prior on adult female survival was specified to allow non-zero probability density only between 0.8 and 0.97 (Thomas 2018). However, recent estimates from Sable Island suggest adult female survival may be above this upper bound. den Heyer

& Bowen (2017) used a Cormack-Jolly-Seber model to estimate age- and sex-specific adult survival from a long-term brand re-sighting programme on Sable Island. Average female adult survival was estimated to be 0.976 (SE 0.001), averaged over all animals, but was higher for younger adults (0.989 with SE 0.001 for age classes 4-24) than older adults (0.904 SE 0.004 for age 25+). Thus, as agreed by SCOS in 2018, the upper limit has been increased to 0.98; the resulting distribution is a beta distribution Be(1.79, 1.53) which is scaled (multiplied by 0.18 and added to 0.8) to allow non-zero probability density only between 0.8 and 0.98. The resulting distribution has mean 0.90 and SD 0.04.

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

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

Fecundity $\boldsymbol{\alpha}$

Relevant studies are summarized in Table 3. For the purposes of this model, fecundity refers to the proportion of breeding-age females (aged 6 and over) that give birth to a pup in a year (natality or birth rate). For the most part, studies have measured pregnancy rather than natality rates. The resulting estimates are thus maxima in terms of fecundity as abortions will cause pregnancy rates to exceed birth rates. Mean estimated adult female pregnancy rates from examination of shot animals were between 0.83 and 0.94 in the UK (Boyd, 1985; Hewer, 1964), and between 0.88 and 1 at Sable Island, Canada (Hammill & Gosselin, 1995). A recent study in Finland (Kauhala *et al.* 2019; Kauhala and Kurkilahti 2020) based on shot animals showed pregancy rate can fluctuate significantly (between c.0.6 and c.95) in relation to the environment (prey quality). CMR studies report lower estimates, which may be a result of unobserved pupping events (due to mark misidentification, tag loss, or breeding elsewhere), but also because such estimates represent births rather than pregnancy. Such studies, from Sable Island estimate fecundity to be between 0.57 and 0.83 (Bowen, Iverson, McMillan, & Boness, 2006; den Heyer & Bowen, 2017). A recent study from Sable Island demonstared that fecundity varied as a function of your breeding status in the previous year: non-breeder, first-time breeder, and breeder (in order of lowest to highest). UK estimates of fecundity rates for populations of marked study animals, adjusted for estimates of unobserved pupping events were 0.79 (95% CI 0.77-0.81) and 0.82 (95% CI 0.79-0.84) for a declining (North Rona) and increasing (Isle of May) population, respectively (Smout et al., 2019). Based on the available data, the prior on fecundity (α) is specified as a beta distribution Be(2, 1.5) which is scaled (multiplied by 0.4 and added to 0.6) to only allow probability density between 0.6 and 1. The resulting distribution has mean 0.83 and SD 0.09.

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

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

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

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

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

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

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

The pup production estimates at colony level from aerial survey data generally have a coefficient of variation of 10% or less. Uncertainty in the ground count estimates is not quantified. The resulting uncertainty in pup production at the region level is hard to predict – if the colony estimates were independent it would be smaller, but they are not independent since they share some parameters. Hence a moderately diffuse prior was specified on ψ (Ga(2.1,66.67), implying a prior on CV of pup production (which is $1/\psi$) of 10% with SD 5 (i.e., with 90% of the prior probability density between 5% and 20%).

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

Age class	females			males			Total n	Time period	Data	Location	Considerations	Source
	mean	uncertainty	n	mean	uncertainty	n						
Pup	0.66		1036	0.66		294		1972, 1975	Aged shot individuals	Farne Islands, UK	Accounted for effect of previous culls on sample structure. Based on life tables.	Harwood & Prime 1978
Pup	0.65	95% CIs: 0.39 - 0.85	180	0.50	95% CIs: 0.25 – 0.75	182		1997 - 1999	CMR (hat tag)	Isle of May and Farne Islands, UK	Tag loss accounted for. Telemetry data used to inform re-sighting probability	Reanalysis of data from Hall, McConnell & Barker 2001; Hall, McConnell & Barker 2002; grey pup seal telemetry data (Carter et al., 2017)
Pup	0.54	95% CIs: 0.18 - 0.86	27	0.43	95% CIs: 0.11 – 0.82	28		2002	CMR (telemetry data)	Isle of May, UK	Tag loss accounted for	Reanalysis of data from Hall, Thomas & McConnell 2009
Pup	0.76 0.55			0.38 0.53			1185 2295	2000 - 2004 2005 - 2009	Aged shot individuals	Baltic	Samples assumed representative. Based on life tables	Kauhala, Ahola & Kunnasranta 2012
≤ 4	0.735 0.331	SE = 0.016 SE = 0.024	1700 1182					1985 - 1989 1998 - 2002	CMR (brand)	Sable Island, Canada	Includes the data from Schwarz & Stobo (2000)	den Heyer, Bowen & Mcmillan 2014
Adult	0.95		239					1956 - 1966	Aged shot individuals	UK	Samples assumed representative. Based on life tables	Data from Hewer 1974, analysed by Lonergan 2012
≥ 10				0.80		294		1972, 1975	Aged shot individuals	Farne Islands, UK	Accounted for population trajectory. Assumed samples are representative within focal age class.	Harwood & Prime 1978
≥ 7	0.935 (0.90-0.96)		1036					1972, 1975	Aged shot individuals	Farne Islands, UK	As above	Harwood & Prime 1978 (reanalysed by Lonergan 2012)
Adult	0.94	95% CIs: 0.93 - 0.95	273					1987 - 2014	CMR (brand, flipper tag, photo ID)	Isle of May	Tag loss and differential sighting probability accounted for. Survival confounded with permanent emigration	Smout, King & Pomeroy, 2019
Adult	0.896	95% CIs: 0.87 - 0.90	584					1993 - 2013	As above	North Rona, UK	As above	As above
≥4	0.976	SE = 0.001	3178			1727		1969 - 2002	CMR (brand)	Sable Island, Canada	Tagged as pups. Confounded with permanent emigration (rare)	den Heyer & Bowen 2017
4-24	0.989	SE = 0.001	As above	0.970	SE = 0.002	As above		As above	As above	As above	As above	As above

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

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

Rate	**Mean**	**Uncertainty**	**n**	**Time period**	**Data**	**Location**	**Considerations**	**Source**
Pregnancy	0.93		79	1956 - 1963	Shot samples			Hewer 1964
Pregnancy	0.94	95% CIs: 0.89 - 0.97	140	1979 - 1981	Shot samples	Farne Islands, UK		Boyd 1985
Pregnancy	0.83	95% CIs: 0.74 - 0.89	88	1978	Shot samples	Outer Hebrides, UK		Boyd 1985
Pregnancy	0.88-1		526	1968 - 1992	Shot samples	Canada	Aged ≥ 6 years old	Hammill & Gosselin 1995
Birth	0.73	0.015	174	1983 - 2005	CMR (brand)	Sable Island, Canada	Aged 4-15 years. Unobserved pupping not considered (likely rare)	Bowen *et al.* 2006
Birth	0.83	0.034	32	1983 - 2005	As above	As above	Aged 16-25 year Unobserved pupping not considered (likely rare)	As above
Birth	0.57	0.03	39	1983 - 2005	As above	As above	Aged 26-35 years Unobserved pupping not considered (likely rare)	As above
Birth	0.790	95% CIs: 0.77 - 0.82	584	1993 - 2013	CMR (brand, flipper tag, photo ID)	North Rona, UK	Accounted for unobserved pupping	Smout *et al.* 2019
Birth	0.82	95% CIs: 0.79 - 0.84	273	1987 - 2014	CMR (brand, flipper tag, photo ID)	Isle of May, UK	As above	As above
Birth	0.79		1727	1992 - 2002	CMR (brand)	Sable Island, Canada	Estimated transitions: unobserved to breeder = 0.41 - 0.64, breeder to breeder = 0.76 – 0.89	den Heyer & Bowen 2017
Birth	0.56		66	2001-2018	Shot/bycatch samples	Finland	Age 5-6 years old	Kauhala and Kurkilahti 2020
Birth	0.79		460	2001-2018	Shot/bycatch samples	Finland	Age 7-24 years old	Kauhala and Kurkilahti 2020

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The status of UK harbour seal populations in 2019 including summer counts of grey seals.

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Abstract

In August 2019, during the harbour seal moult, the Sea Mammal Research Unit (SMRU) carried out helicopter surveys using a thermal imager in Orkney, Shetland, and along the northern section of the Moray Firth from Duncansby Head to Helmsdale. The 2019 survey completed the round-Scotland harbour seal survey which started in 2016. Part of the Moray Firth and the Firth of Tay and Eden Estuary SAC are surveyed annually by fixed-wing.

The annual SMRU fixed-wing surveys in England cover the Lincolnshire and Norfolk coasts. The Zoological Society of London carries out annual surveys of the wider Thames area. Various different organisations around England and Wales contribute additional local counts. For areas that weren't surveyed between 2016 and 2019 older data or estimates were used to create country-level totals.

From the most recent August surveys, carried out mainly between 2016 and 2019, the minimum number of harbour seals counted in Scotland was **26,846**, and in England & Wales it was **3,886**. Including **1,012** harbour seals counted in Northern Ireland in 2018, the UK harbour seal total count for this period was **31,744**.

Grey seals are counted during harbour seal surveys although grey seal counts can vary more than harbour seal counts during the summer months. From the most recent August surveys, carried out mainly between 2016 and 2019, the number of grey seals counted in Scotland was **25,412**, and in England & Wales it was **16,848**. Including **505** grey seals counted in Northern Ireland in 2018, the UK grey seal total count for this period was **42,765**.

Introduction

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

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

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

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

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

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

Methods

Seals hauling out on rocky or seaweed covered shores are well camouflaged and difficult to detect. Surveys of these coastlines in Scotland are carried out by helicopter using a thermal-imaging camera which is able to detect groups of seals at distances of over 3km (depending on weather conditions). This technique enables rapid, thorough and synoptic surveying of seals inhabiting complex coastlines. Previously, since 2007, oblique photographs were obtained using a hand-held camera equipped with an image-stabilised zoom lens. Groups of both harbour and grey seals were digitally photographed and the images used to classify the species composition of all groups of seals. The grey seal counts from these surveys have been used elsewhere to inform the models used to estimate the total grey seal population size (Russell *et al*., 2016).

Since August 2016, a new custom-built, 3-camera system, based on Trakka System's SWE-400, has been used to survey seals in August. The system consists of a gyro-stabilised gimbal containing a thermal imaging camera, a colour video camera, a high-resolution digital still camera equipped with a 300mm telephoto lens, and a laser range finder. Video and still images are recorded onto laptops which display a moving map, highlighting areas of coast that have already been searched during the survey.

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

To maximise the counts of seals on shore and to minimise the effects of environmental variables, surveys are restricted to within two hours before and two hours after the time of local low tides (derived from POLTIPS, National Oceanographic Centre, NERC) occurring between approximately 12:00 and 19:00. Surveys are not carried out in persistent or moderate to heavy rain because seals will increasingly abandon their haul-out sites and return into the water, and because the thermal imager cannot 'see' through rain.

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

Results and Discussion

1. UK totals

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

The overall distribution of harbour seals around the UK from August surveys carried out between 2016 and 2019 is shown in Figure 1. For ease of viewing at this scale, counts have been aggregated by 10km squares.

The most recent minimum harbour seal population estimates for UK Seal Management Units (SMUs) in 2016-2019 are provided in Table 1 and are compared with four previous periods (1996-1997, 2000-2006, 2007-2009, and 2011-2015).

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

The most recent minimum estimate of the number of harbour seals in Scotland, obtained from counts carried out between 2016 and 2019, is **26,846** (Table 1). This is just over 5% higher than the previous Scotland census in 2011-2015, but is still close to 10% lower than the highest Scotland total counted in 1996-1997 (29,514; Table 1). Since 2001, harbour seal counts have declined in Shetland, Orkney and along the north and east coasts of Scotland (Lonergan *et al*., 2007; Thompson *et al.*, 2019) while counts in the West Scotland SMU appear to have increased.

The most recent minimum estimate for England & Wales, obtained from surveys carried out mainly in 2019, is **3,886** (Table 1). This is around 25% lower than the three totals obtained for 2016, 2017, and 2018 that ranged from 5,095 to 5,202. It is the lowest total in around ten years (Table 1).

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

The sum of all the most recent counts carried out between 2016 and 2019 gives a UK total of **31,744** harbour seals (Table 1). This is slightly higher than the UK count for 2011-2015 (31,218), and is around 6% lower than the highest UK total in 1996-1997, assuming a count of approx. 1,000 harbour seal in Northern Ireland.

1.2. Grey seals in the UK in August

Grey seals are counted in all harbour seal surveys but, because grey seal counts are significantly more variable than harbour seal counts in August, they have not previously been fully reported. In conjunction with grey seal telemetry data, the grey seal summer counts from 2007-2009 and 2011-2015 have been used to calculate an independent estimate of the size of the grey seal population (Lonergan *et al*. 2011; Russell *et al*., 2016). August grey seal counts will be used similarly in future.

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

The most recent count of grey seals in Scotland, obtained from August surveys carried out mainly between 2016 and 2019 is **25,412** (Table 2). This is 9% higher than the total Scotland count obtained from August surveys between 2011 and 2015.

There were **15,168** grey seals counted in eastern England in 2018 and 2019. Combined with an estimate of **1,680** in West England & Wales and the 2018 count of **505** in Northern Ireland (Table 2), the most recent UK total count of grey seals in August is **42,765**.

2. Aerial surveys in Scotland in August 2019

The parts of Scotland surveyed in August 2019 by helicopter using a thermal imager were: Orkney, Shetland, and the coastline from Duncansby Head down to Helmsdale. Parts of this northern section of the Moray Firth had not been surveyed since 2008 or 2011, because the timing of low water made it difficult to fit it in with other surveys, and the low numbers of seals found here meant that it was not a high priority area. In 2019, it was finally possible to survey this stretch of coast during the return flight from Shetland to Inverness. The annual fixed-wing surveys using hand-held photography covered the western part of the Moray Firth between Helmsdale and Findhorn, as well as the Firth of Tay and Eden Estuary SAC.

Figure 3 shows the years when different parts of the Scottish coast were last surveyed. The 2019 survey completed a fifth round-Scotland survey since 1996. Harbour seal counts from the most recent surveys in 2016-2019 and from four previous survey periods (1996-1997, 2000-2006, 2007-2009, and 2011-2015) are in Table 1.

The most up-to-date August distribution of harbour seals in Scotland, from surveys between 2016 and 2019, is shown in Figure 4. The trends in counts of harbour seals in different Seal Management Areas in Scotland, from surveys carried out between 1991 and 2019 are shown in Figure 5.

The most up to date August distribution of grey seals in Scotland, from surveys between 2016 and 2019, is shown in Figure 6. Grey seal counts from the most recent surveys and from four previous periods (1996-1997, 2000-2006, 2007-2009, and 2011-2015) are in Table 2.

2.1. Orkney (9-12 August 2019)

Orkney was surveyed twice during the last round-Scotland census period. In 2016, 1,240 harbour seals were counted, and **1,296** in 2019 (Table 1). These are the two lowest counts to date, around 85% lower than the highest count in 1997 (8,522). Although the 2019 count was not lower than the preceding count for the first time since the decline began in the early 2000s, this may be due to the variation in the proportion of animals hauled out during surveys, and the decline could still be ongoing.

The 2019 grey seal count for Orkney was **8,185**. This is close to the average count for 8 out of the 9 surveys carried out since 1997 (approx. 8,500; range: ~7,100-9,600). A low grey seal count in 2001 (2,913) was the exception, and was likely due to unusually wet weather conditions preceding the survey days that year.

2.2. Shetland (12-17 August 2019)

The harbour seal count for Shetland in 2019 was **3,180** (Table 1). This is very similar to the average of 3,150 for the three previous counts carried out between 2006 and 2015 (range: 3,038-3,369). These counts obtained over the last 15 years are all close to 50% lower than the highest Shetland total recorded in 1993 (6,227).

The grey seal counts in Shetland have been relatively stable over the last 25 years, averaging around 1,500. The 2019 count of **1,009** was the lowest count of this period (Table 2).

2.3. Moray Firth, partly (15, 17 August 2019)

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

Between Helmsdale and Findhorn, **1,025** harbour seals were counted in 2019 (Table 3). The highest count was recorded in 1997 (1,407), the first time this area was counted in a single survey. The average August count since annual coverage began in 2005 is just under 900. Although the total counts for this area have not been following a clear trend over the last 20 years, there are some obvious local trends (Figure 8). The Dornoch Firth SAC contributed 42% to the highest 'Helmsdale to Findhorn' total count in 1997. Since then, the number of harbour seals found in the SAC have continued to decline, contributing only 6% in 2019 (Figure 7). In contrast, Culbin Sands has become the main haul-out area in the Moray Firth. In the late 2000s, fewer than a dozen harbour seals were generally found there. Since then, counts have continued to increase, and Culbin contributed 57% (588) to the total 'Helmsdale to Findhorn' harbour seal count in 2019.

In the annually surveyed part of the Moray Firth (Helmsdale to Findhorn) **1,564** grey seals were counted in 2019 (Table 4). This is around 10% lower than the highest count recorded in 2010 (1,751). In the 1990s, the vast majority of grey seals were found in the Outer Dornoch. Similarly to harbour seals, the number of grey seals using haul-out sites at Culbin and at Findhorn has increased dramatically, and 55% of grey seals counted in 2019 were found here (456 and 400 respectively).

2.4. Firth of Tay and Eden Estuary SAC (22 August 2019)

The harbour seal count for the Firth of Tay and Eden Estuary SAC in 2019 was **41** (Table 5). This is almost identical to the average count for 2013-2018 (43; range: 29-60). There is still no sign that this population is recovering following the dramatic decline observed in the 2000s (Figure 10). In the 1990s and early 2000s, large groups containing 100-200 harbour seals were found on the sandbanks at Tentsmuir and in the Eden estuary. More recently, harbour seals are mainly found in very small groups in the Firth of Tay (Figure 9). The 2019 count is around 95% lower than the highest count recorded in 1992 (773).

In the Firth of Tay and Eden Estuary SAC in 2019, **686** grey seals were counted (Table 6). The grey seal total for the SAC has always been dominated by the number of animals hauled-out at Tentsmuir/Abertay. Over 2,000 individuals were counted on these sandbanks in 2000, and an average of 1,250 between 1990 and 2012. Since then, this average has dropped to <600 (range: 323-738), contributing only 80% to the total SAC count, compared to 93% for 1990-2012.

3. Aerial surveys in Southeast England in 2019

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

The great majority of English harbour seals are found in the Southeast England SMU (Figure 1). In 1988, the previously increasing numbers of harbour seals in The Wash declined by approximately 50% as a result of the phocine distemper virus (PDV) epidemic. Following the epidemic, from 1989, the area has been surveyed once or twice annually in the first half of August (Table 7, Figure 11). After recovering to 1988 levels by 2001, the population was hit by another PDV outbreak in 2002. It was reduced by around 20% but recovered to pre-epidemic levels by 2012.

One aerial survey of harbour seals was carried out by SMRU in Lincolnshire and Norfolk during August 2019. The 2019 count for the coast between Donna Nook and Scroby Sands (**3,081**) was 27.6% lower than the 2012-2018 average (~4,250, range: 4,170-4,367; Table 7). This was mainly due to the lowest August count for The Wash in ten years. However, occasionally there are very low counts that cannot be excluded if there are no overt signs of disturbance, e.g. in 2010, two surveys carried out within one week of each other produced very different results (3,179 and 1,992). The next surveys will show whether or not the 2019 count indicates an actual and significant decline.

The Zoological Society of London carried out a survey of the Essex and Kent coast, where **671** harbour seals were counted compared with an average of 742 for the three surveys in 2016-2018, and an average of 474 for the three surveys in 2013-2015 (Table 7; Cox *et al.*, 2020).

The combined counts for the Southeast England Seal Management Unit (Flamborough Head to Newhaven) in 2019 (**3,752**) was 25% lower than the average for the three previous totals in 2016-2018 (approx. 5,000; Table 7). The counts in the Wash and North Norfolk SAC were similarly lower in 2019 (Figure 11).

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

A total of **8,677** grey seals were counted in the Southeast England SMU between Donna Nook and Dover in August 2019 (Table 2). This is very similar to the totals recorded in the previous two years (Table 8). The grey seal count in this SMU has increased tenfold over the past 15 years, the biggest increase for either species in any UK SMU since August surveys began.

4. Harbour seal data available for other areas

In Northern Ireland, August helicopter surveys are carried out approximately every six years, using the same methods as the thermal imager surveys in Scotland. The last survey was conducted in 2018 and produced a total count of 1,012 harbour seals, similar to the average from three previous census periods (1,075, Table 1; Morris & Duck, 2019). A total of 505 grey seals were counted during the survey in 2018.

In Northeast England, harbour seals in the Tees Estuary have been monitored by the Industry Nature Conservation Association (INCA) since 1989. Following a slow increase in numbers from an average of 43, in 2003-2008, to an average of 88 in 2015-2017, the last two years both produced mean August counts of **76** harbour seals (Bond, 2019). An average of **14** grey seals were counted in August 2019.

In the Solent, in South England, Langstone Harbour Board & Chichester Harbour Conservancy have been carrying out dedicated harbour seal surveys around Langstone and Chichester since 2015. More recently, small numbers have been recorded by National Trust volunteers in the Newtown National Nature Reserve on the Isle of Wight. In August 2019, an average of **40** harbour seals and **17** grey seals were counted in the Solent.

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

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

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Table 1. The most recent August counts of harbour seals at haul-out sites in the British Isles by Seal Management Unit compared with four previous periods. The grey values given for SMUs 10-13 are rough estimates.

Seal Management Unit / Country			Harbour seal counts 1996-1997	2000-2006	2007-2009	2011-2015	2016-2019
1	Southwest Scotland		929	623	923	1,200	1,709
2	West Scotland	a	8,811	11,666	10,626	15,184	15,600
3	Western Isles		2,820	1,920	1,804	2,739	3,532
4	North Coast & Orkney		8,787	4,388	2,979	1,938	1,405
5	Shetland		5,994	3,038	3,039	3,369	3,180
6	Moray Firth		1,409	1,028	776	745	1,077
7	East Scotland		764	667	283	224	343
SCOTLAND total			29,514	23,330	20,430	25,399	26,846
8	Northeast England	b	54	62	58	91	79
9	Southeast England	c	3,222	2,964	3,952	4,740	3,752
10	South England	d	10	15	15	25	40
11	Southwest England	d	0	0	0	0	0
12	Wales	d	2	5	5	10	10
13	Northwest England	d	2	5	5	5	5
ENGLAND & WALES total			3,290	3,051	4,035	4,871	3,886
NORTHERN IRELAND total		e		1,176	1,101	948	1,012
UK total				27,557	25,566	31,218	31,744
REPUBLIC OF IRELAND total		f		2,955		3,489	4,007
BRITAIN & IRELAND total				30,512		34,707	35,751

SOURCES - Most counts were obtained from aerial surveys conducted by SMRU and were funded by Scottish Natural Heritage (SNH) and the Natural Environment Research Council (NERC). Exceptions are:

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

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

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

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

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

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

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

Seal Management Unit / Country			Grey seal counts				
			1996-1997	2000-2006	2007-2009	2011-2015	2016-2019
1	Southwest Scotland		75	206	233	374	517
2	West Scotland	a	3,435	2,383	2,524	5,064	4,174
3	Western Isles		4,062	3,674	3,808	4,085	5,773
4	North Coast & Orkney		9,427	10,315	8,525	8,106	8,599
5	Shetland		1,724	1,371	1,536	1,558	1,009
6	Moray Firth		551	1,272	1,113	1,917	1,657
7	East Scotland		2,328	1,898	1,238	2,296	3,683
SCOTLAND total			21,602	21,119	18,977	23,400	25,412
8	Northeast England	b	613	1,100	2,350	6,942	6,501
9	Southeast England	c	417	2,266	1,786	5,637	8,667
10	South England	d		2	2	5	30
11	Southwest England	d		425	425	500	500
12	Wales	d		750	750	850	900
13	Northwest England	d		30	30	50	250
ENGLAND & WALES total				4,573	5,343	13,984	16,848
BRITAIN total				25,692	24,320	37,384	42,260
NORTHERN IRELAND total		e		272	243	468	505
UK total				25,964	24,563	37,852	42,765
REPUBLIC OF IRELAND total		f		1,309		2,964	3,698
BRITAIN & IRELAND total				27,273		40,816	46,463

SOURCES - Most counts were obtained from aerial surveys conducted by SMRU and were funded by Scottish Natural Heritage (SNH) and the Natural Environment Research Council (NERC). Exceptions are:

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

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

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

d No SMRU surveys, but some data available. Estimates compiled from counts shared by other organisations (Langstone Harbour Board & Chichester Harbour Conservancy, Natural England, Natural Resources Wales, RSPB, 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; Woodfin Jones, 2019). Apparent increases may partly be due to increased reporting.

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

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

Table 3. August counts of harbour seals in the annually surveyed western Moray Firth between Helmsdale and Findhorn. Mean values are given for areas surveyed more than once in a single season. The difference in fill-opacity reflects the size of a count relative to all subarea counts in the table. See Figure 7 for the 2019 distribution of seals within the Moray.

Area	1992	1994	1997	2000	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
	fw	fw	ti	fw	fw&ti	fw	2fw	2fw&1ti	fw&ti	fw&ti	fw&ti	fw	fw	ti	fw	fw	fw	fw	ti	fw	fw	fw
Helmsdale to Brora			193		188			113	150	54	73	19	101	87	102	70	1	21	40	22	30	17
Loch Fleet			27	33	59	56	64	71	80	83	82	65	114	113	133	135	156	144	145	138	152	109
Dornoch Firth	662	542	593	405	220	290	231	191	257	144	145	166	219	208	157	143	111	120	85	39	117	62
Cromarty Firth	41	95	95	38	42	113	88	106	106	102	90	90	140	101	144	63	100	22	72	20	43	84
Beauly Firth	220	203	219	204	66	151	178	127	176	146	150	85	140	57	60	30	37	34	30	5	30	24
Ardersier		221	234	191	110	205	202	210	197	154	145	277	368	195	183	199	28	34	36	81	98	116
Culbin & Findhorn		58	46	111	144	167	49	93	58	79	92	73	123	163	254	218	260	330	484	526	444	613
Total			1,407		829			911	1,024	762	777	775	1,205	924	1,033	858	693	705	892	831	914	1,025

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

Table 4. August counts of grey seals in the annually surveyed western Moray Firth between Helmsdale and Findhorn. Mean values are given for areas surveyed more than once in a single season. The difference in fill-opacity reflects the size of a count relative to all subarea counts in the table. See Figure 7 for the 2019 distribution of seals within the Moray.

Area	1992	1994	1997	2000	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
	fw	fw	ti	fw	fw&ti	fw	2fw	2fw&1ti	fw&ti	fw&ti	fw&ti	fw	fw	ti	fw	fw	fw	fw	ti	fw	fw	fw
Helmsdale to Brora			3		6			111	102	52	449	72	635	156	316	81	27	161	28	201	147	191
Loch Fleet			0	0	0	0	0	0	1	3	1	0	7	7	20	18	7	10	31	22	15	17
Dornoch Firth	233	903	456	121	321	79	473	431	748	516	523	819	717	679	74	604	127	716	387	273	321	401
Cromarty Firth	9	0	0	0	0	0	0	0	1	0	0	0	1	2	1	3	1	0	1	0	0	0
Beauly Firth	8	2	3	8	0	0	0	0	3	4	0	0	2	3	1	5	2	0	2	0	1	1
Ardersier		36	24	85	0	3	44	55	142	74	142	94	331	74	24	109	2	14	28	87	83	98
Culbin & Findhorn		0	0	0	0	10	0	11	11	28	75	58	58	179	121	218	93	743	717	548	144	856
Total			486		327			608	1,008	677	1,190	1,043	1,751	1,100	557	1,038	259	1,644	1,194	1,131	711	1,564

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

Table 5. August counts of harbour seals in the annually surveyed Firth of Tay and Eden Estuary SAC. Mean values are given for areas surveyed more than once in a single season. The difference in fill-opacity reflects the size of a count relative to all subarea counts in the table. See Figure 9 for the 2018 distribution of seals within the SAC and Figure 10 for a histogram of these data.

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

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

Table 6. August counts of grey seals in the annually surveyed Firth of Tay and Eden Estuary SAC. Mean values are given for areas surveyed more than once in a single season. The difference in fill-opacity reflects the size of a count relative to all Subunit counts in the table. See Figure 9 for the 2018 distribution of seals within the SAC.

Area	1990	1991	1992	1994	1997	2000	2002	2003	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
	1fw	1fw	1fw	1fw	1ti	1fw	1fw	1fw	2fw,1ti	1fw	1fw,1ti	2fw	1fw	1fw	1fw	1fw	1ti	1fw	1fw	1ti	1fw	1fw	1fw
Upper Tay	0	0	18	20	61	64	78	50	42	22	27	26	55	98	16	39	127	62	115	132	78	52	43
Broughty Ferry	0	3	0	9	0	0	0	16	0	8	1	8	0	0	2	3	0	2	0	0	0	0	0
Buddon Ness	0	0	1	104	0	101	0	33	11	25	85	7	0	12	22	13	18	0	2	0	0	0	0
Tentsmuir	912	1,546	1,191	1,335	1,820	2,088	1,490	1,560	763	1,267	1,375	483	395	1,406	1,265	1,111	323	531	687	738	596	667	561
Eden Estuary	0	0	16	0	10	0	25	4	27	57	31	33	0	39	17	36	14	39	32	66	76	46	82
SAC total	912	1,549	1,226	1,468	1,891	2,253	1,593	1,663	843	1,379	1,519	557	450	1,555	1,322	1,202	482	634	836	936	750	765	686

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

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

SOURCES - Counts from SMRU aerial surveys using a fixed-wing aircraft funded by NERC except where stated otherwise:
Northumberland - One complete survey in 2008 (funded by DECC (prev. DTI). Helicopter surveys with thermal imager from Farne Islands to Scottish border in 1997, 2005, 2007, 2015, and 2018. Fixed-wing surveys of Holy Island only in 1994 & 2000.
The Tees - Ground counts by Industry Nature Conservation Agency (Bond, 2020). Single SMRU fixed-wing count in 1994.
Other sites - St Mary's Island, Ravenscar, Filey Brigg (SMRU aerial surveys).
Essex & Kent - 2013-2017 and 2019 surveys carried out by the Zoological Society of London (Barker & Obregon, 2015; Cox *et al.*, 2020).

Table 8. August counts of grey seals in the Northeast and Southeast England Seal Management Units. Mean values are given for areas surveyed more than once in a single season. Grey values indicate that a small proportion of the area wasn't surveyed.

	Northeast England			Southeast England						
Year	N'umber -land	The Tees	Other sites	Donna Nook	The Wash	Blakeney Point	Horsey	Scroby Sands	Essex & Kent	SE total
1988					52	1				
1989		7								
1990		9		115	10					
1991		8			48					
1992		9		235	35	6				
1993		9		59	64	7				
1994	*100*	6		100	94	40		43		
1995		10		123	66	18		32		
1996		11		119	60	11		46		
1997	*603*	10		289	49	45		34		
1998		11		174	53	33		23		
1999		12		317	57	14		89		
2000	*568*	11		390	40	17		40		
2001		11		214	111	30		70		
2002		12		291	75	11				
2003		11		232	58	18		36	96	440
2004		13		609	30	10		93		
2005	*1,092*	12		927	49	86		106		
2006		8		1,789	52	142		187		
2007	*1,907*	8		1,834	42					
2008	2,338	12		2,068	68	375		137	160	2,807
2009		12		1,329	118	22		157		
2010		14		2,188	240	49		292	393	3,161
2011		14		1,930	142	300		323		
2012		18		4,978	258	65		126		
2013		16		3,474	219	63		219	203	4,178
2014		16		4,437	223	445		509	449	6,063
2015	*6,767*	16		3,766	369	528		520	454	5,637
2016		22	60	3,964	431	355		642	481	5,872
2017		27		6,526	688	502		425	575	8,716
2018	6,427	15		6,288	253	360	205	497	596	8,199
2019		14		5,265	540	635	119	1,333	775	8,667

SOURCES - Counts from SMRU aerial surveys using a fixed-wing aircraft funded by NERC except where stated otherwise:
Northumberland - One complete survey in 2008 (funded by DECC (prev. DTI). Helicopter surveys with thermal imager from Farne Islands to Scottish border in 1997, 2005, 2007, 2015, and 2018. Fixed-wing surveys of Holy Island only in 1994 & 2000.
The Tees - Ground counts by Industry Nature Conservation Agency (Bond, 2020). Single SMRU fixed-wing count in 1994. For years prior to 2005, only monthly maximums are available for grey seals. For these years, the given values are estimates calculated using the mean relationship of mean to maximum counts from 2005-2013.
Other sites - St Mary's Island, Ravenscar, Filey Brigg (SMRU aerial surveys).
Essex & Kent - 2013-2017 and 2019 surveys carried out by the Zoological Society of London (Barker & Obregon, 2015; Cox *et al.*, 2020).

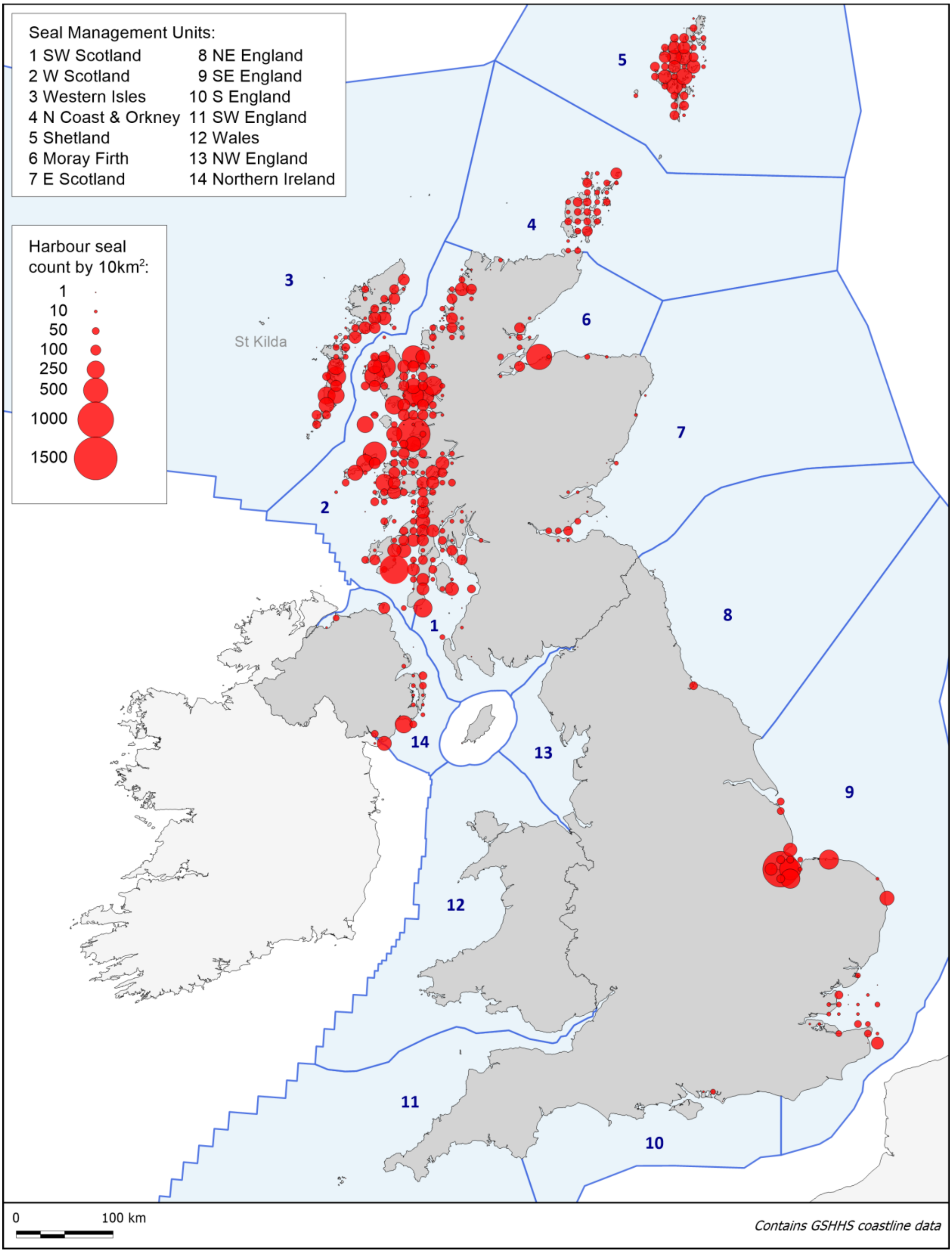

Figure 1. August distribution of harbour seals around the British Isles by 10km squares based on the most recent available haul-out count data collected up until 2019. Limited data available for SMUs 10-13; no data available for St Kilda.

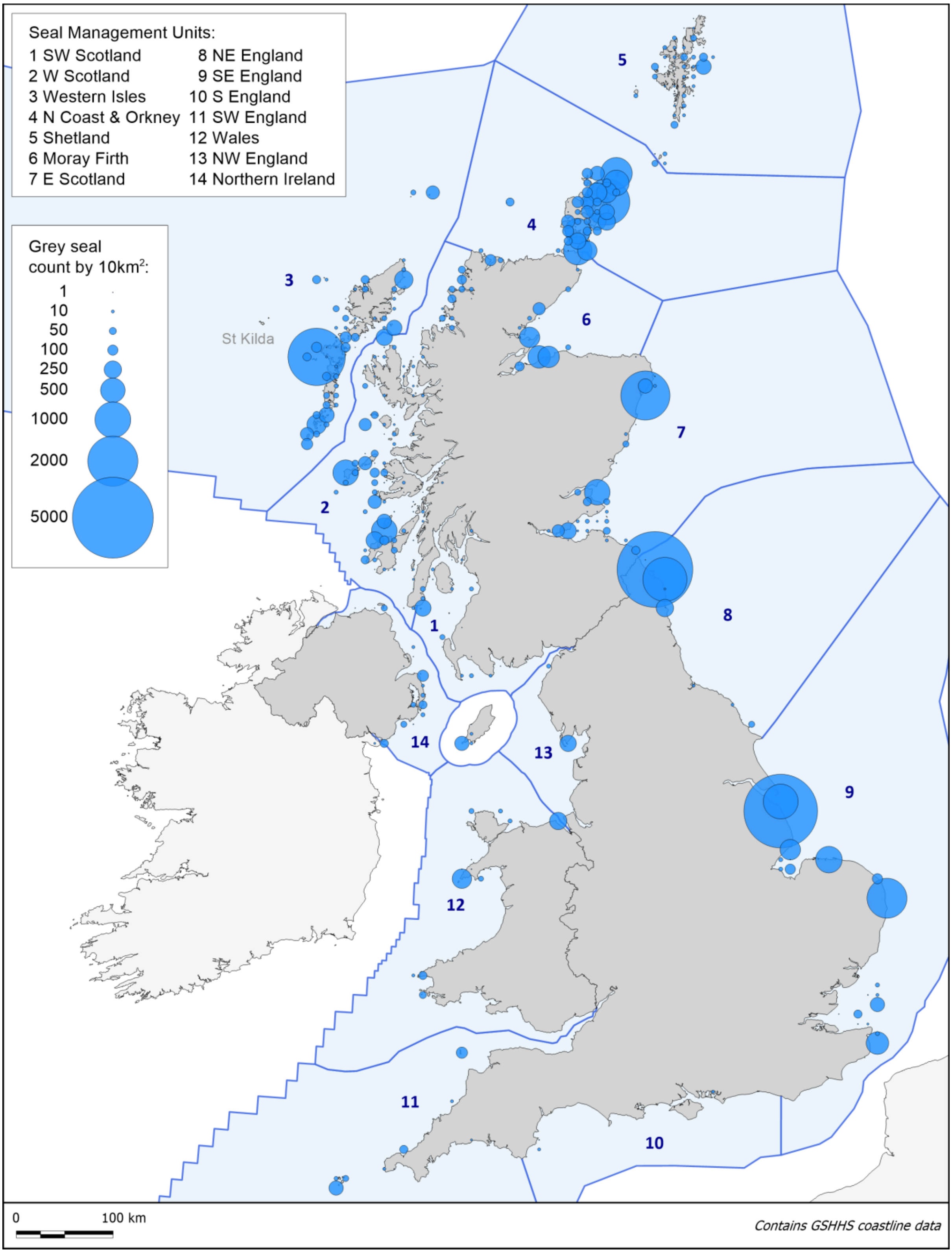

Figure 2. August distribution of grey seals around the British Isles by 10km squares based on the most recent available haul-out count data collected up until 2019. Limited data available for SMUs 10-13; no data available for St Kilda.

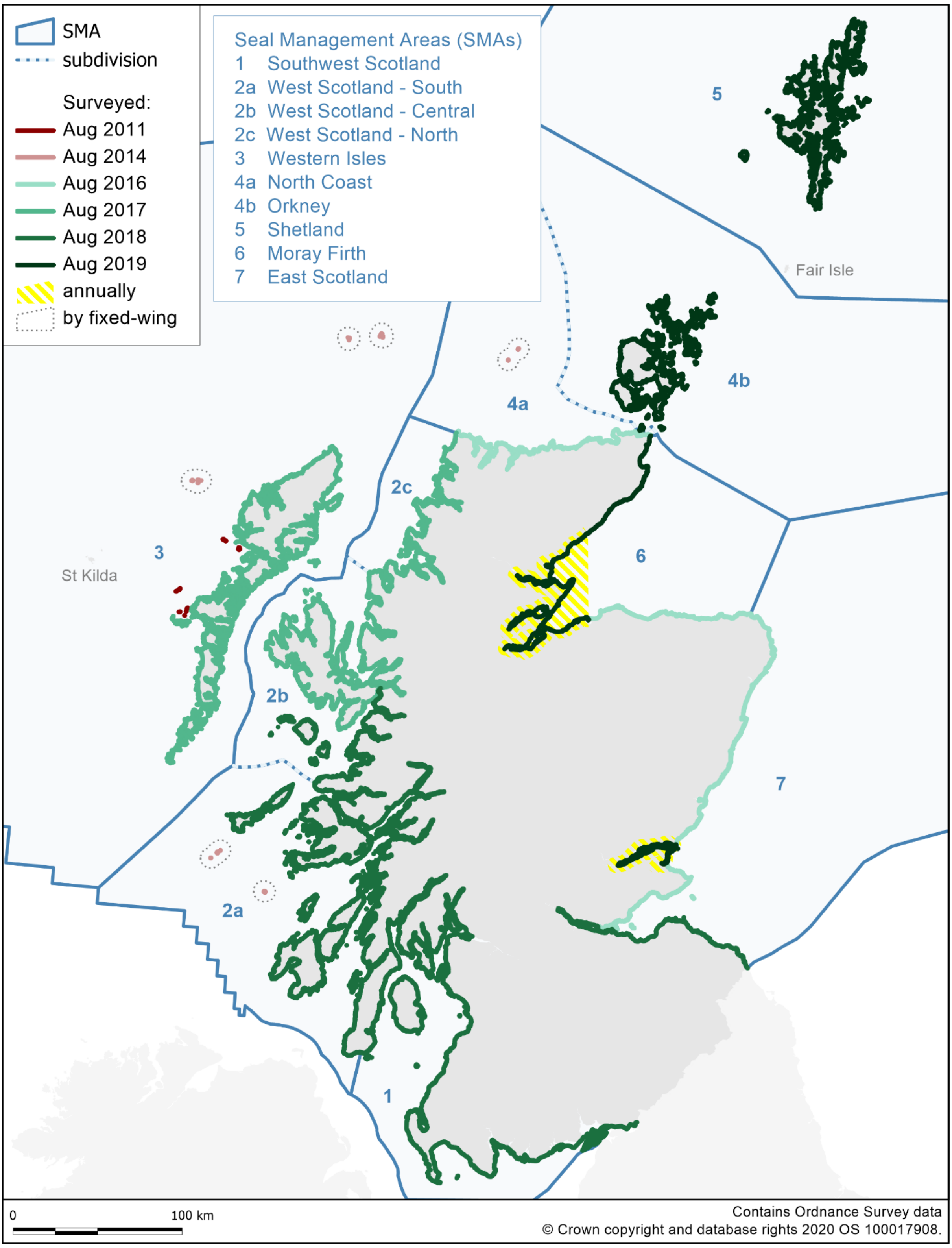

Figure 3. Map showing when the most recent aerial surveys were carried out during the harbour seal moult in August. Most areas were last surveyed between 2016 and 2019. The yellow shaded areas of the Firth of Tay and the Moray Firth (between Helmsdale and Findhorn) are surveyed every year, usually by fixed-wing aircraft. Offshore islands were last surveyed in 2014 by fixed-wing aircraft. However, only very small numbers of harbour seals are found on islands last surveyed pre-2016. St Kilda and Fair Isle have not been covered properly by aerial surveys.

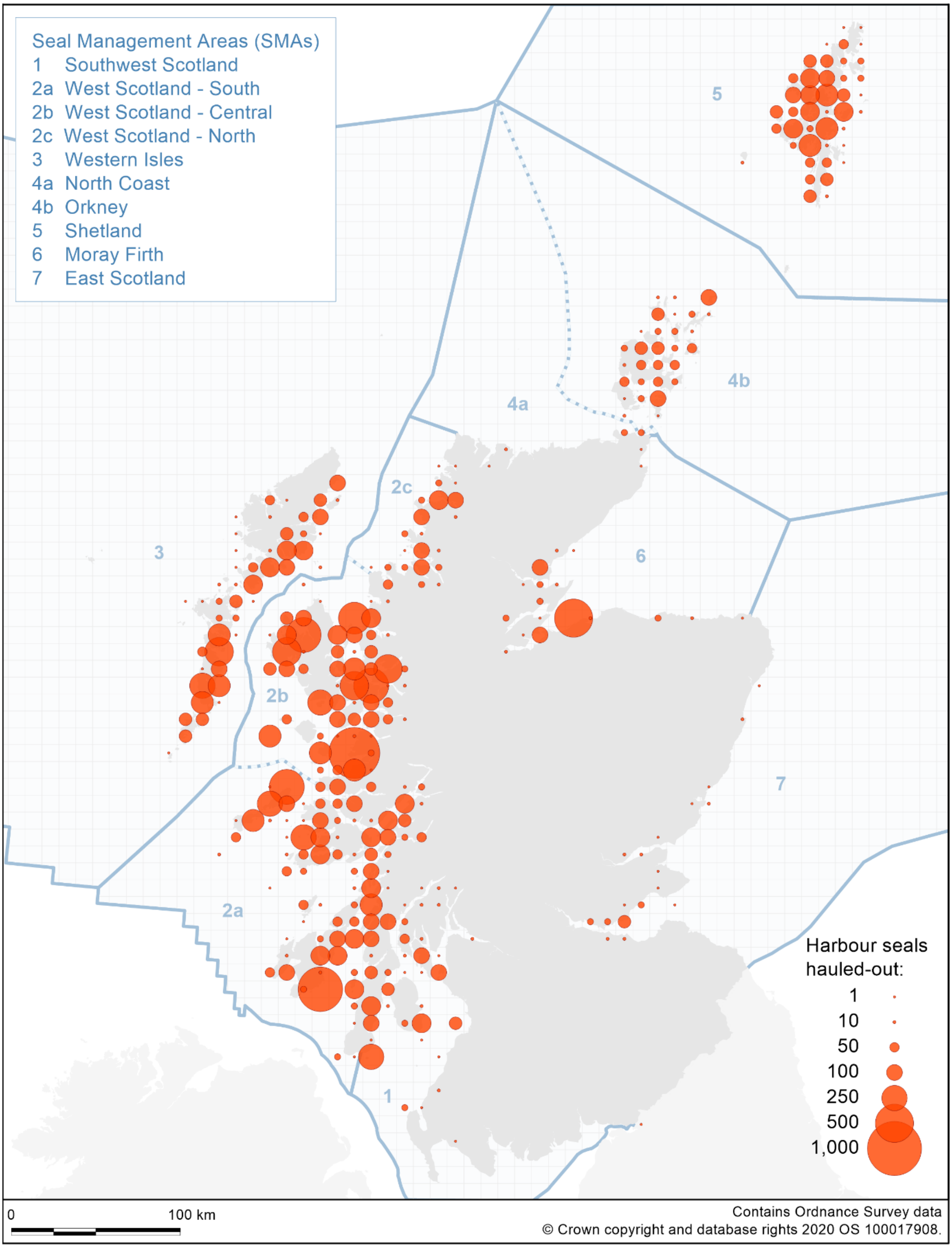

Figure 4. Map of harbour seal distribution by 10km squares based on haul-out counts obtained from the most recent aerial surveys carried out during the harbour seal moult in August 2016-2019.

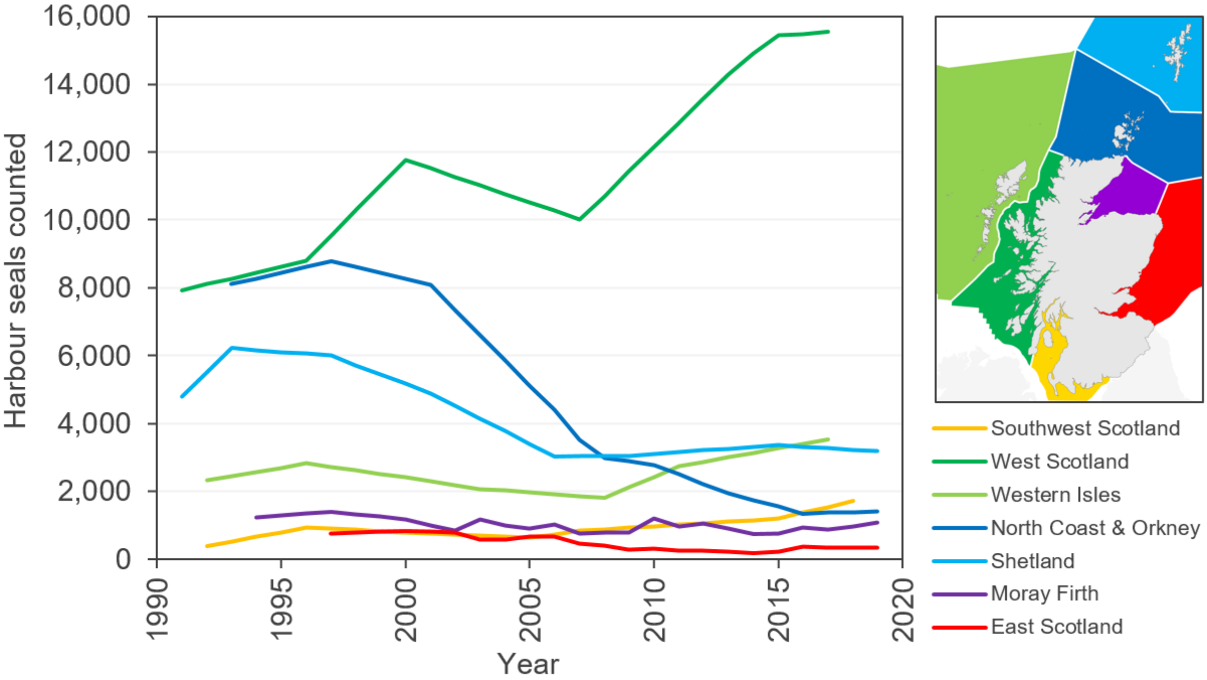

Figure 5. Comparison of August harbour seal counts in Scottish Seal Management Areas (SMAs) from 1991 to 2019. Because SMA totals represent counts of seals distributed over large areas, individual data points may contain counts made in more than one year. Interpolated values are used for years with incomplete coverage.

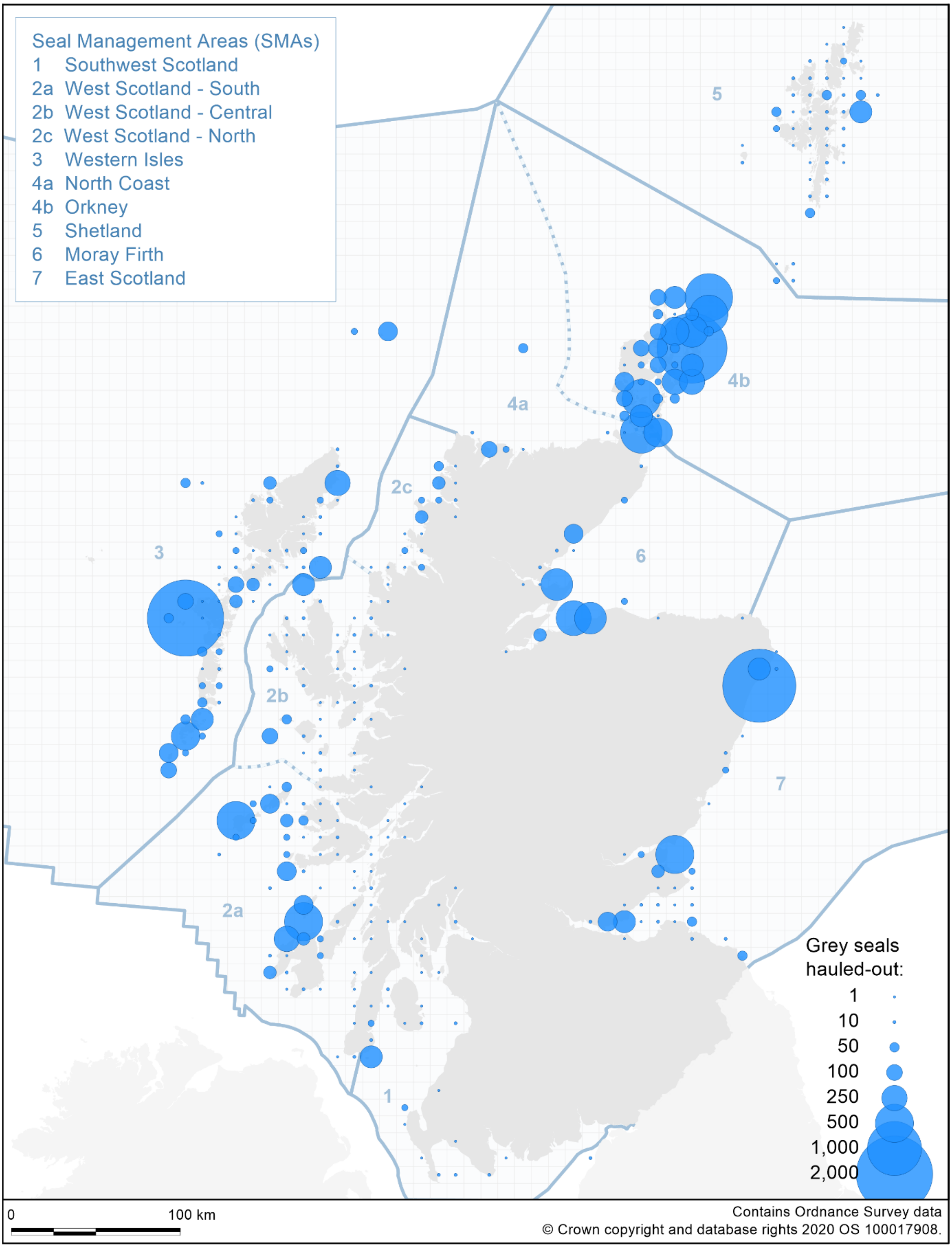

Figure 6. Map of grey seal distribution by 10km squares based on haul-out counts obtained from the most recent aerial surveys carried out during the harbour seal moult in August 2016-2019.

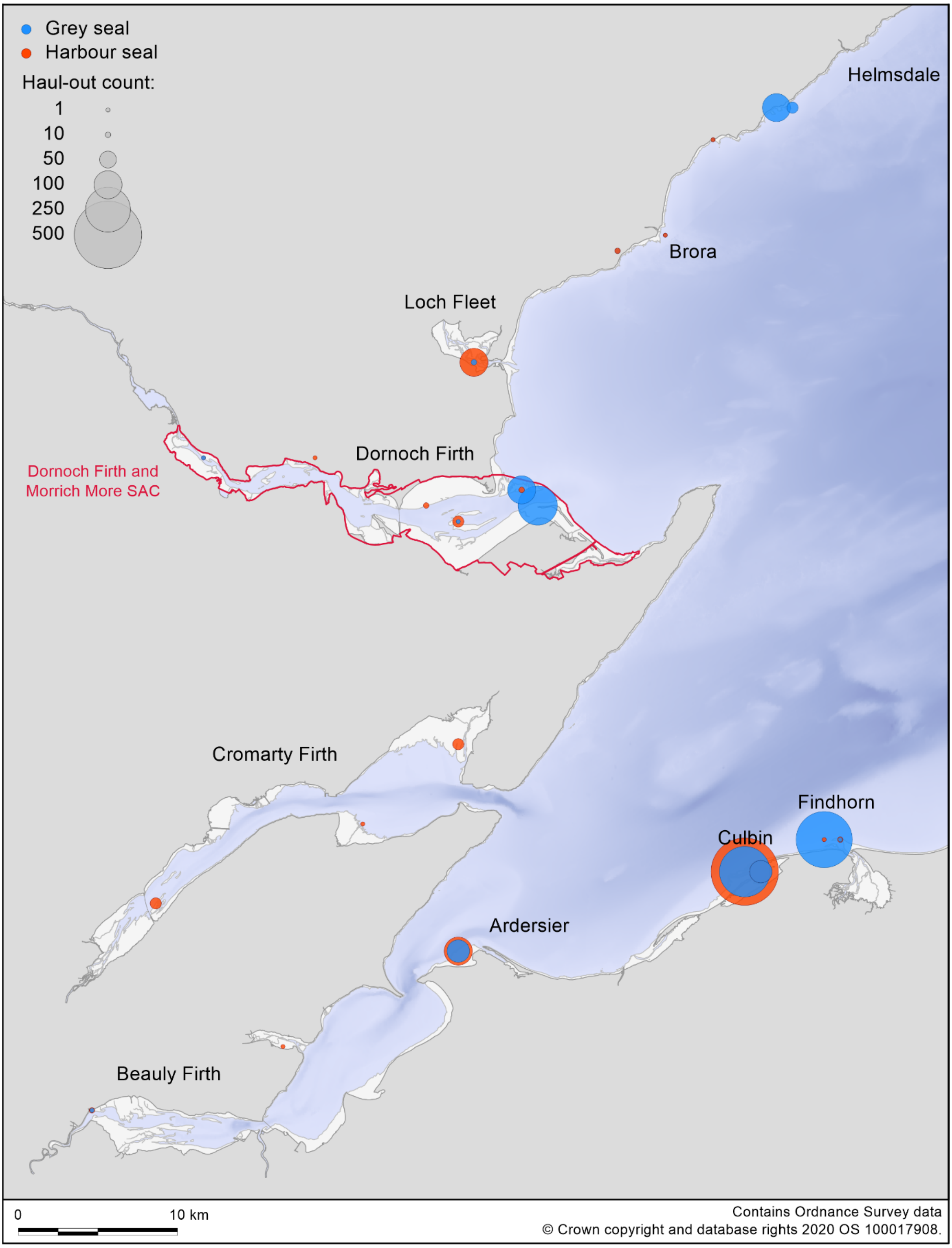

Figure 7. Distribution of harbour (red) and grey seals (blue) in the annually surveyed western Moray Firth, between Helmsdale and Findhorn, from an aerial survey carried out on 15th August 2019.

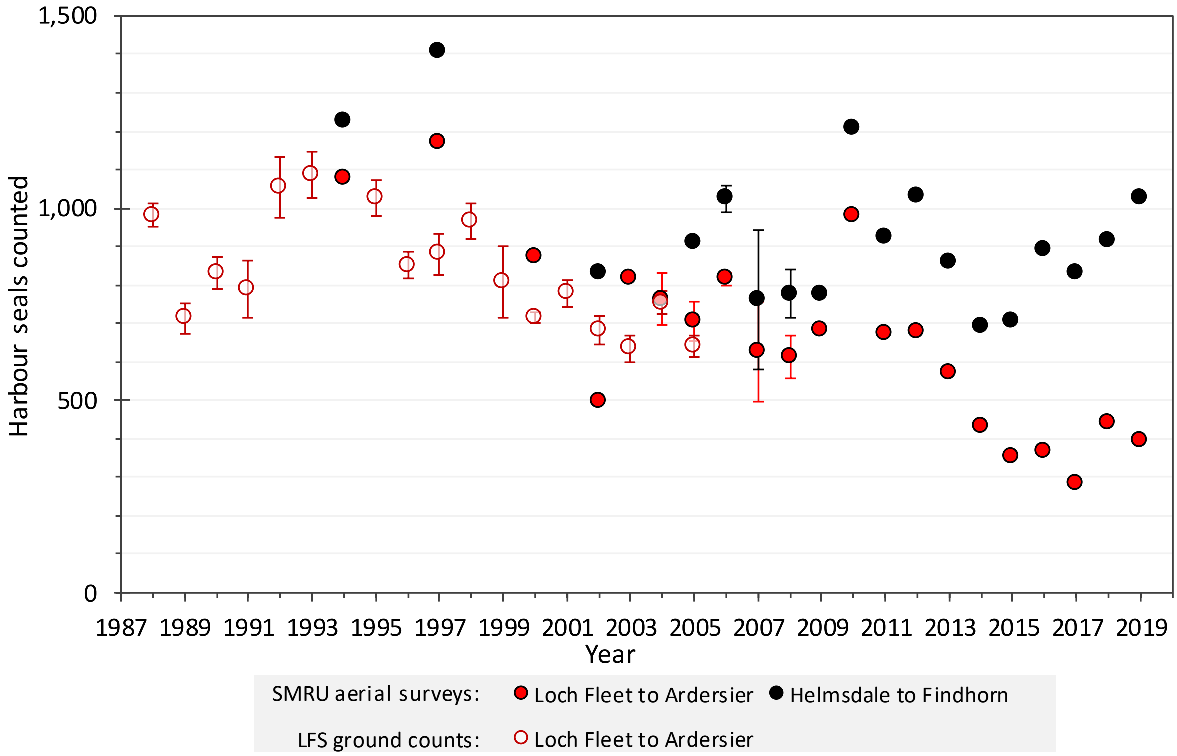

Figure 8. Counts of harbour seals in the western Moray Firth during the moult season in August 1988-2019. Plotted values are means ±SE where available. LFS = Lighthouse Field Station (University of Aberdeen).

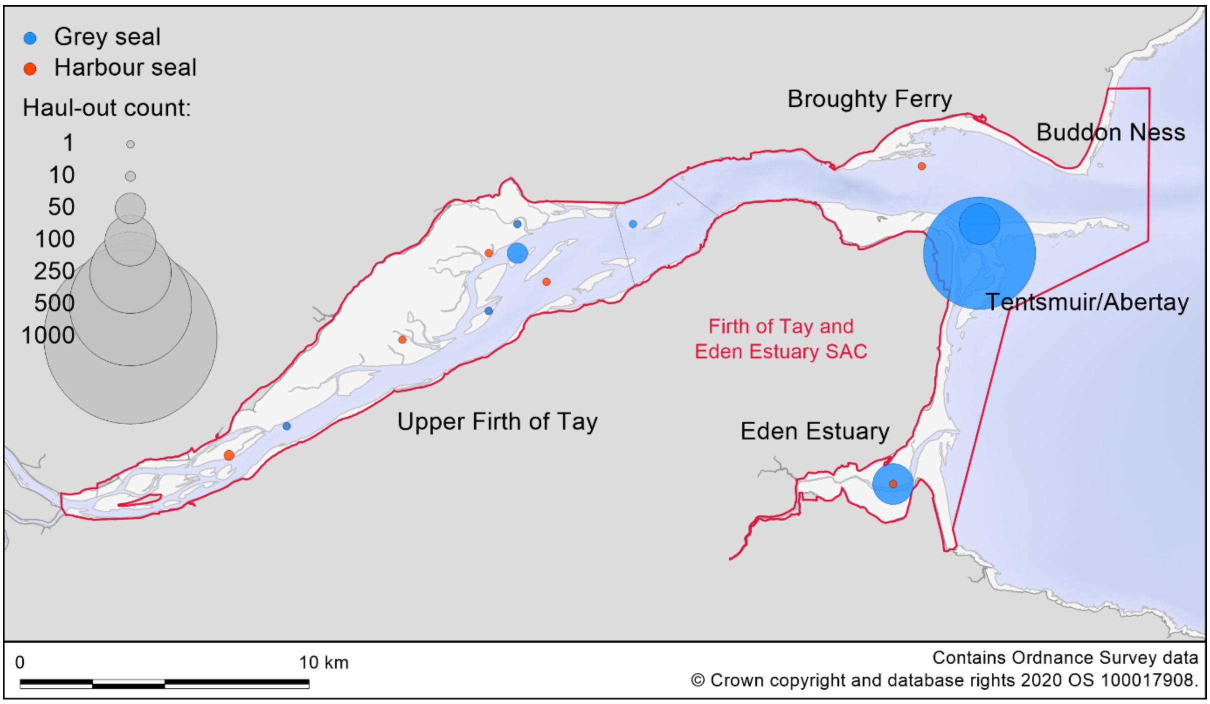

Figure 9. The distribution of harbour (red) and grey seals (blue) in the annually surveyed Firth of Tay and Eden Estuary SAC on 22nd August 2019.

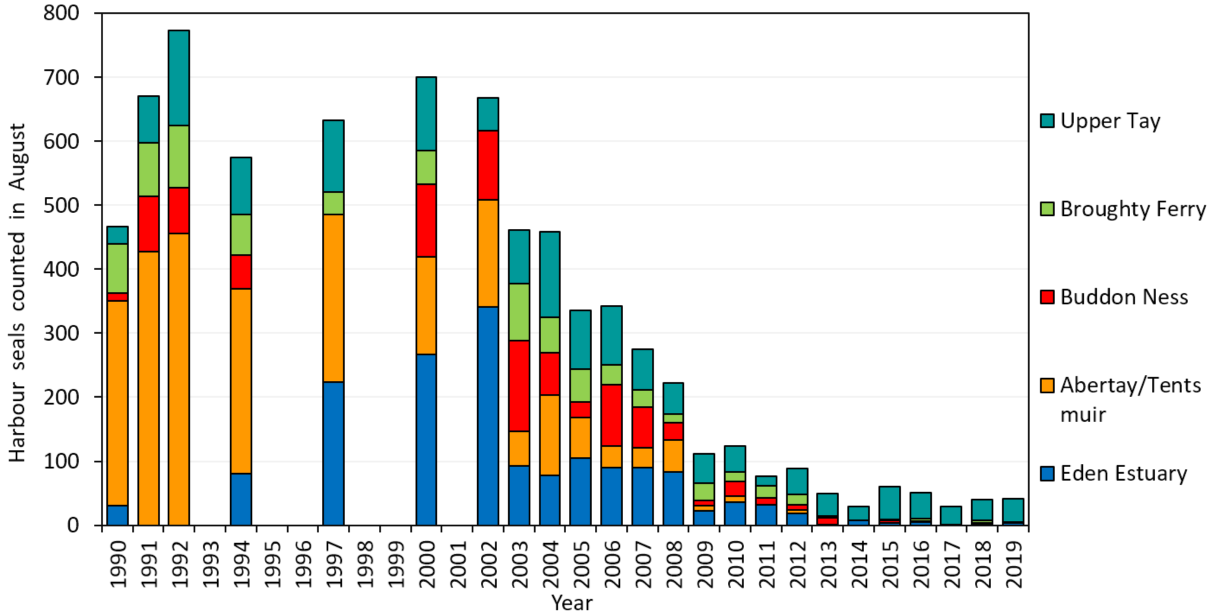

Figure 10. August counts of harbour seals in the Firth of Tay and Eden Estuary SAC, 1990 to 2019.

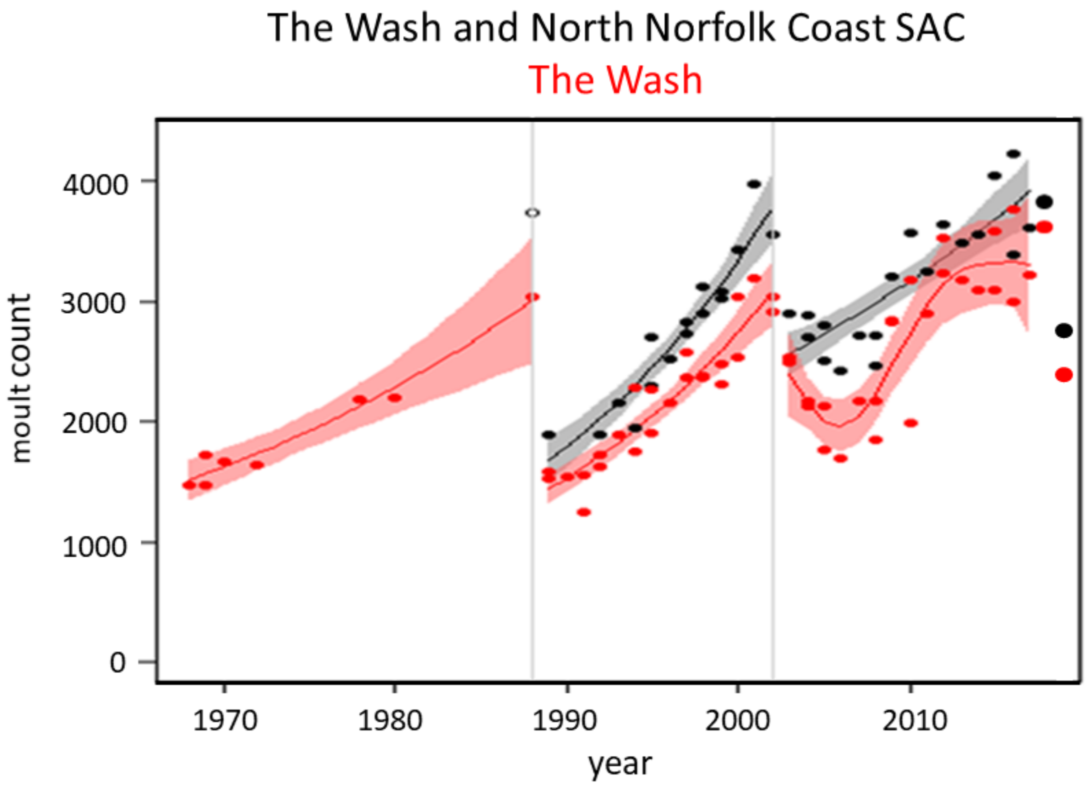

Figure 11. *Trends in harbour seals counts in The Wash (red) and the combined Wash and North Norfolk SAC, between 1967 and 2017 (shaded areas indicate the 95% confidence intervals for the fitted curves). For further explanation see text and Thompson et al. (2019). 2018 counts were similar to the previous 5 year's counts, but the 2019 count was approximately 25% lower.*

Grey seal population of Southwest UK & Northern Ireland

Seal Management Units 10-13

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Abstract

In response to NRW Q1 and Defra Q1, the status of the grey seal population in the southwest UK and Northern Ireland is examined in this briefing paper. These areas encompass five Seal Management Units (SMUs): 10. South England, 11. Southwest England, 12. Wales and 13. Northwest England, and 14. Northern Ireland. Data from these SMUs are not included in the population model which is currently used to estimate grey seal population size. Instead, the estimated proportion of UK pup production from colonies that are not incorporated in the population model (SMUs 10-14: 3.8 %; non regularly monitored Scottish colonies: 6.7%) is used to scale the model output to generate a UK grey seal population estimate. The population model is based on two sets of data: (1) a region-specific time series of pup production, and (2) overall (i.e. not region-specific) estimates of grey seal population size from August surveys (hereafter 'independent estimates' because they are independent from the pup production data) pertaining to 2008 and 2014. Here the relevant data from SMUs 10-14 are examined and the feasibility of extending the population model to incorporate these SMUs is discussed.

Based on available data, it was estimated that current pup production (2019) in SMUs 10-14 is c. 2,900. This, using the most up-to-date data for the rest of the UK (2016-2019 for regularly monitored colonies), equates to c. 4.4% of UK pup production. There are no SMU-wide recent estimates of pup production for Wales or Northern Ireland. To generate a robust estimate of pup production in SMU 12, the scalars (used to scale from indicator sites to larger areas) used to estimate pup production would need to be updated for West Wales (last surveyed in 1994). Although there are time-series of pup production data from a subset of colonies (e.g. Bardsey Island, Skomer Marine Conservation Zone, Lundy Island), incorporating these in the population model would require a robust scalar between such colonies and less regularly monitored colonies, as well as data on August counts. Indeed, the lack of robust SMU-wide summer haul-out counts for SMUs 11 and 12, is another barrier to the inclusion of SMUs within the population model. Generating such counts would be challenging due to the substantial proportion of the population that haul out in caves. In recognition that the population model does not pertain to a closed population, ideally it should be extended to cover the whole of the UK (and the northeast Atlantic). However, extending the population model to SMUs 10-14 would not enhance our understanding of the population in these SMUs, or the UK as a whole.

Background

The purpose of this briefing paper is to address NRW Q1 and Defra Q1, as well as provide an update on our current understanding of grey seal population in the southwest UK and Northern Ireland. These areas encompass five Seal Management Units (SMUs): 10. South England, 11. Southwest England, 12. Wales and 13. Northwest England, and 14. Northern Ireland (Figure 1). Currently, data from these SMUs do not directly feed into the population model that is used to provide annual estimates of UK population size (Thomas 2020). The population model is based on two sets of data: (1) a region-specific time series of pup production, and (2) overall (i.e. not region-specific) estimates of grey seal population size from August surveys (hereafter 'independent estimates' because they are independent from the pup production data) pertaining to 2008 and 2014. The pup production estimates cover regularly monitored colonies within four regions of the UK (Figure 1). In contrast, the independent estimate covers Scottish and east English coasts (SMUs 1-9; Figure 1). Thus, to allow comparable data to be used in the population model, the proportion of pup production in SMUs 1-9 which is from regularly monitored colonies is used to scale down the independent estimate so that it more closely matches the scale of the pup production estimates. For example, the 2008 independent estimate was multiplied by 0.9234 (the proportion of pup production at regularly monitored colonies in Scotland and eastern England (SMUs 1-9)).

The output of the population model provides region-specific trends in pup production and abundance. It does not provide region-specific absolute estimates of pup production or abundance – the estimates pertain only to regularly monitored colonies. The estimated proportion of UK pup production from colonies that are not incorporated in the population model (SMUs 10-14: 3.8 %; non regularly monitored Scottish colonies: 6.7%; SCOS 2019) is used to scale the model output to generate a UK grey seal population estimate. In this briefing paper, the available pup production data and August counts are reviewed, and the feasibility of extending the population model to incorporate these SMUs is discussed.

Data

In order to address NRW Q1, SMRU approached NRW (T Stringell) to provide the following information for Wales: (1) summer count data (August when available but other months if not), (2) pup production estimates, and (3) pup counts. The provided data and reports augment the data previously supplied by NRW and Natural England in response to requests from SMRU. For all SMUs, available counts and pup production estimates were also sourced from publications and websites. In addition, data regularly supplied to SMRU by Chichester Harbour Conservancy (SMU 10) and Cumbria Wildlife Trust (SMU 11) were also considered.

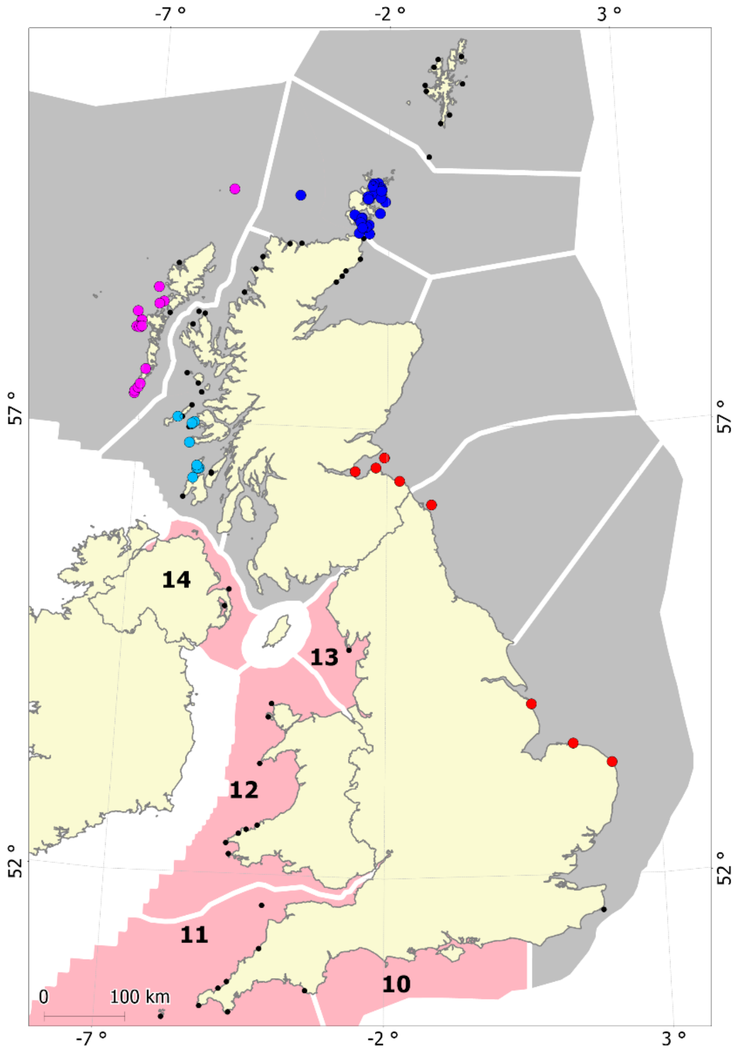

Figure 1. UK Seal Management Units (SMUs) with grey seal colonies shown as points (note not all pupping sites are shown). SMUs in grey are those included in the independent population estimate and coloured points indicate regularly monitored colonies (from which pup production is included in the population model). SMUs in pink are the focus of this briefing paper.

Grey seal population

SMU 10: South England

No grey seal pups are known to be born in this SMU. A small number of grey seals are seen in this SMU; they mainly use haul-out sites in the Solent and around Dartmouth and Brixham. Monitoring of seals in the Solent is coordinated by the Chichester Harbour Conservancy with assistance from Langstone Harbour Board, National Trust and others. Further monitoring and research is underway as part of a collaboration between the Chichester Harbour Conservancy and Sarah Marley at the University of Portsmouth. Seals in Brixham Harbour are monitored by The Seal Project, and areas around Dartmouth have been surveyed by Stephen Westcott. There is indication of an upward trend in numbers in recent years, but numbers are still low (total SMU August count estimate of around 30 grey seals).

SMU 11: Southwest England

The monitoring of seals in this SMU is primarily conducted by Cornwall Seal Group Research Trust (CSGRT) and the Lundy Company. Pup production for mainland Cornwall was estimated to be c. 150 pups in 2019 (compared to c. 110 in 2016; Sayer and Witt 2017a; Sayer, Millward, Witt 2020), and c. 230 (range: 221 - 234) for the Isles of Scilly in 2016 (compared to 89 -134 in 2010; Sayer, Hockley and

Witt 2012; Sayer and Witt 2017b). The main breeding colony in Devon is on Lundy (43 pups in 2019; Jones 2020), with only a few (5; Sayer and Witt 2017a) recorded on the mainland. Based on the latest available data, and rounding up to the nearest 50, pup production for this SMU is estimated to be c. 450. Although there was a previous survey of this SMU (Westcott 2008) in 2005, the resulting estimates were “tentative”, and thus SMU wide changes in pup production cannot be quantified. Furthermore, some of the sites can only be surveyed by boat, and the proportion of the pups recorded by Westcott (2008) which were at sites surveyed vs non-surveyed for Sayer and Witt (2017a) is unclear. However, there is clearly evidence of increasing pup production detected by CSGRT surveys, notwithstanding the changes in survey effort highlighted in the reports.

There have been no synoptic surveys during August, but combining counts from multiple sources (Jones 2020; Leeny *et al.* 2010; Sayer 2011, Sayer 2012a; 2012b; 2012c; Sayer, Hockley and Witt 2012;), generated an August count of c.625 individuals

SMU 12: Wales
Monitoring of grey seals in Wales is split into two areas: North Wales (Dee Estuary- Aberystwyth) and West Wales (Aberystwyth - Caldey Island). There are no or very few grey seals in south Wales (Caldey Island – Bristol Channel). Intensive monitoring of pup production is primarily focussed at three sites: Bardsey Island (North Wales; Porter unpub. data), parts of Ramsey Island (West Wales; Engbo *et al.* 2020), and Skomer Marine Conservation Area (MCZ, West Wales; Engbo *et al.* 2020; Wilkie and Zbijewska 2020). Other areas have been monitored more sporadically, and within a season, less intensively.
North Wales wide surveys have been conducted in 2001 (Westcott 2002), 2002 (Westcott and Stringell 2003) and 2017 (Robinson *et al*. In Prep). The latest pup production estimate for 2017, including dead pups but assuming all moulted pups were counted previously or were born elsewhere (see Carter *et al.* 2017 for Welsh pup movements), was 216.
West Wales wide surveys were conducted in 1992, 1993, and 1994 (Baines 1995). It is not possible to estimate trends in pup production on a SMU scale. Pup production at Ramsey Island indictor sites has been variable but shown little trend (Morgan 2019). There is an upward trend in pup production at Skomer MCZ, though the trend is variable (Wilkie and Zbijewska 2020).
We used scalars between pup production in West Wales and indicator sites (in mainland north Pembrokeshire sites, Ramsey Island, and Skomer MCZ), in 1993 and 1994, to generate a total pup production estimate for West Wales. It should be noted, this was generated using the most recent available estimates for indicator sites, rather than predictions from fitted trends at these sites. Combined with the most recent estimate of North Wales, and rounding up to the nearest 50, this results in a pup production estimate of c. 2,250. Almost half half of the SMU estimate of pup production is from sites not surveyed since the early 1990sTo produce a robust estimate of pup production, scalars between indicator sites and irregularly monitored colonies need to be updated. This is particularly important when there are multiple habitat types (e.g. caves, open beaches) in an area. Cryptic sites (such as caves, small coves) can often support much smaller colonies and thus their trends, especially in the longer term, may differ from more open sites that are also easier to monitor. Indeed, for North Wales, Robinson *et al.* (In Press) found that a much lower proportion of pup production was at cryptic sites than found previously (Stringell *et al.* 2014).

Thus, clearly there is a considerable uncertainty around this estimate. There are two comprehensive datasets relating to August counts: Bardsey Island (Porter unpub. data) and Hilbre Island (Hilbre Bird Observatory); both of which show increasing numbers with mean counts in August 2019 of 174 and 285, respectively. For other areas, data are more sporadic with historic data indicating mean August counts of c. 100 and 57 for Ramsey (2014; Morgan unpub. data) and Skomer (2019; Wilkie and Zbijewska 2020), respectively. Combined with mean August counts for the North Wales (excluding Bardsey Island; Westcott 2002, Westcott and Stringell 2004), generates at total count of c. 800, though this is likely to be a gross underestimate given the lack of data from West Wales mainland, the age of data from some sites, and the upward trends at well-monitored sites.

SMU 13: Northwest England

There are two main haulouts of grey seals in SMU 11; one in the Dee Estuary on the Welsh-English border (Hilbre Island discussed above), and South Walney. At South Walney, Cumbria Wildlife Trust and Walney Bird Observatory have historically conducted counts of the seals primarily during the breeding and molting seasons. These data indicate that grey seal abundance is steadily increasing. Starting in 2019, Cumbia Wildlife Trust have conducted low tide counts in August to provide SMRU with numbers comparable to those used in the independent estimate of grey seal abundance. In 2019 and 2020, the August count was 248 and 300, respectively. It has been a pupping site since 2015 but numbers are currently still low (2-10 per year).

SMU 14: Northern Ireland

The majority of grey seal pups born in Northern Ireland are born in Strangford Lough. Strangford Lough is monitored by National Trust and numbers have been increasing (Culloch *et al.* 2018) from c. 10 in the early 1990s to 181 in 2019. Monitoring elsewhere is more sporadic and we estimate that up to 250 pups are born in Northern Ireland. August surveys were conducted by SMRU in 2002, 2011 and 2018 (commissioned by the Department of Agriculture, Environment and Rural Affairs, Northern Ireland). The most recent count was 505 individuals (Duck and Morris 2019). There are not enough surveys to estimate a trend but there is an indication of an increasing population: 468 counted in 2011 and 104 counted in 2002 (but see Culloch *et al.* 2018).

Discussion

Monitoring methods

Recent surveys in both North Wales and SW England, found that relatively few pups are born in caves, and thus the error associated with excluding caves is likely low (relative to other sources of error); surveying seals in caves is relatively expensive and can be dangerous , and is associated with high levels of disturbance. However, a substantial proportion of pups are born in caves in some areas (e.g. West Wales). The most suitable method is likely dependent on the site. On mainland Cornwall, <5% of pups were only counted during boat-based surveys (Sayer, Millward and Witt 2020) suggesting that land-based surveys are most appropriate for these areas. Boats may be required for some areas, for example, in North Wales. Drones may be suitable for some sites, though operation of commercial drones usually has to be within line of sight of the operator. Together with other distance restrictions and battery considerations, this limits their utility for larger colonies or stretches of coastline. Drones are currently used to monitor seals at South Walney.

Estimation of pup production

Pup production is estimated in various ways across the considered SMUs, from peak counts to modelled estimates. For example, at some sites, pup production can be directly calculated by ‘following’ individual pups (e.g. Skomer MCZ). This is likely to be the most accurate method and has the added value of allowing calculation of other parameters such as survival rates. However, such methods are labour intensive and are not generally possible at large colonies. The most appropriate technique will depend on the characteristics of the site, and the type and number of surveys that can be conducted within a season. For example, a model can be used to estimate a birth curve (as is done with the aerial survey pup counts). Such models have been used to estimate pup production from staged pup counts on Ramsey for example (Strong 1998). The structure of the current pup production model used by SMRU (Russell et al. 2019) limits the type of survey data that can be input: separate counts of whitecoat (stage I-IV) and moulted pups (stage V), with uni-directional observation error (to account for moulted pups misclassified as whitecoats but not the reverse). It also relies on knowledge of the age at which pups leave the beach which may vary spatially. Nevertheless, any colonies for which there are at least four surveys, and the data format is as above, can be input into the pup production model; more than four surveys are required to allow estimation of other parameters (e.g. age of leaving). Such a model may be useful for sites for which current methods are labour-intensive, requiring > 5 visits and/or involve staging pups (which may be more prone to error compared to simply classifying pups as whitecoat and moulted). More investigation would be required to assess the suitability of data collected, and to allocate observation parameters, but it seems likely that the data collected from Bardsey Island, Ramsey Island, and Skomer MCZ could be input into the SMRU pup production model. Indeed, the level of detail (e.g. individual pups are followed on Skomer) and number of visits would allow estimation of age of leaving and observation parameters. This would allow the model to be adjusted to ensure pup production could be estimated with fewer data points in future years if that was deemed a preferable method. The main consideration in using the pup production model at these sites is that it can only be used with synoptic surveys. In other words, the colony would need to be subsampled to provide a section that could be covered in a single survey day and then the same section of the colony would need to be covered on each survey day, and a birth curve estimated for that section (rather than the island or colony as a whole). Ideally there should be no movement of pups between the surveyed section and other parts of the colony. A state-space model is currently being developed by SMRU to replace the current pup production model. The increased flexibility of this model will facilitate the inputting of different forms of data (e.g. whitecoats only, or non-classed pups). However, this model would still involve generation of a birth curve which requires synoptic surveys of discreet (parts of) colonies. It is not possible to derive a birth curve for very small colonies or in absence of a colony (i.e. stretches of coast). It would therefore not be suitable for estimating pup production in much of mainland Cornwall and north Wales where small numbers of pups are born on long stretches of coast. In such areas, counts of whitecoat pups at three-week intervals can be used to estimate pup production based on the assumption that all whitecoats counted in one survey will have moulted by the second survey. Alternatively, more frequent staged counts can be conducted using the estimated duration of these stages to estimate pup production (see Morgan 2014). However, given the relatively small numbers of pups born in North Wales and Cornwall the cost-benefit of such effort should be considered. Interestingly, the mean duration of stages/classes used in different studies vary, which will have an impact of the estimate of pup production for a given data set. For example, for the SMRU pup production model pups are assumed to be fully moulted by 23 days (SD 5 days; reviewed in Russell *et al.* 2015). In contrast, other studies use different values for this parameter such as 21 days (mean; Morgan 2014) and a range of 17 to 23 days (Sayer and Witt 2017).

Population model

The population model currently incorporates pup production estimates only from regularly monitored colonies, and the equivalent population for the independent estimates (see Background and Figure 1). SMUs 10-14 are not included in the population model. Two sets of data would be required to include these SMUs in the population model: (1) A time-series of pup production estimates. (2) August counts pertaining to 2008 and 2014. The temporal extent and resolution of the pup production data would not need to match those of the regions currently considered. Either a time-series of a subset of sites could be considered (i.e. regularly monitored colonies) or SMU-wide totals estimated by scaling estimates from indicator sites. A key consideration with this would be that a single variance parameter for pup production is estimated within the population model; scaled SMU-wide pup production estimates would likely have much higher uncertainty than current estimates for the other regions. Indeed, for Wales around half of the estimated pup production is from sites that have not been surveyed since the early 1990s. Use of indicator sites for pup production would still require information on the scalar between such sites and SMU-wide pup production, to allow independent estimates to be scaled to represent the same proportion of the SMU as pup production. Indeed, the key difficulty to including these SMUs within the population model is the lack of independent estimates of grey seal population size for 2008 or 2014 that are comparable (and thus can be combined) with the estimates from Scotland and east England; i.e. available counts do not cover the entire region or a known proportion of the population. There are two key issues with generating such estimates: (a) an unknown but potentially substantial proportion of individuals haul out in caves – indeed the vast majority of seals at Ramsey Island (May 2019) were in caves (Carter pers. comm.) (b) The earlier breeding in the southwest may mean August surveys reflect abundance and distribution associated with breeding and thus may not be comparable with the rest of the UK counts. Inaccuracies for the independent estimate for this region would impact on the output of the population model as a whole. At a SMU scale, the sparsity of data means there would be little value in their incorporation into the population model. In a preliminary analysis, conducted for the Marine Strategy Framework Directive Indicator Assessment, the population model was extended to cover the majority of the European grey seal population (Russell *et al.* 2016) for which estimates were generated for pup production in SMUs 10 and 11, and an independent estimate for 2008. Although this model provided overall and unit-specific predicted trends of grey seal population, the confidence intervals surrounding the trends for southwest UK/France were too wide for the output to be of use in a management context (Figure 2).

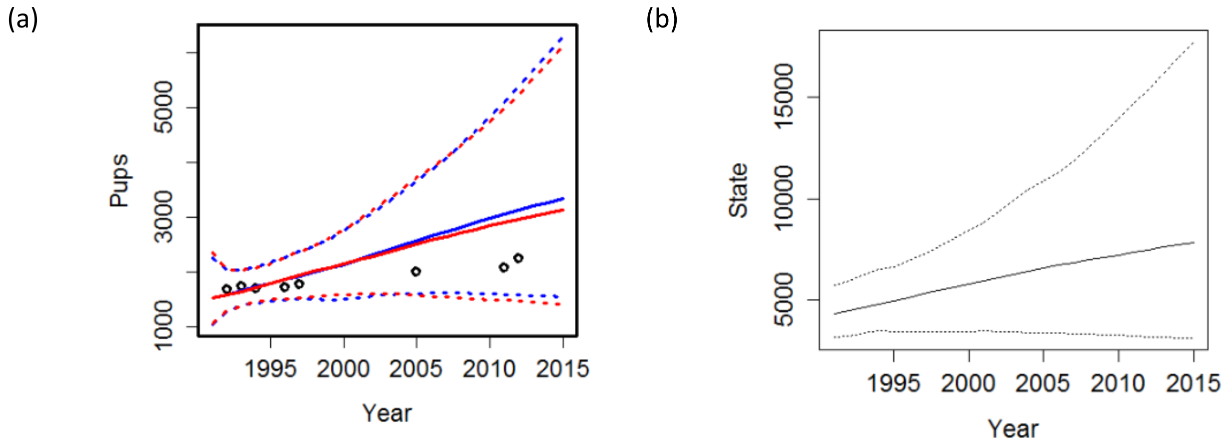

Figure 2. The estimated number of pups (a) and abundance (b) in southwest UK and France. See Russell et al. (2016) for more details.

Conclusions

Combining across SMUs (and rounding up to the nearest 100 to account for missed areas and trends since surveys) we estimate up to 3,000 pups (SMUs 10-14: 0, 450, 2250, 10, 255) are born in SMUs 11-14; 4.4 % of UK pup production. Further work would be required to source and interrogate the data to ensure the estimates of pup production and summer haul out counts presented here were the most robust estimates available.

Given that the area considered in the population model does not represent a closed population, ideally the model should be extended to the UK and also to the rest of the northwest Atlantic population. Such inclusion would also allow the movement of females born at regularly monitored colonies and recruiting elsewhere (e.g. Wales) to be explicitly modelled. Pup production in the Hebrides appears to have reached a carrying capacity (Thomas 2020), and thus pup survival (survival to age one) is estimated to be low (14%; Thomas et al. 2019). However, in reality a substantial number of these pups are likely recruiting into the southwest UK population given that the population appears to be increasingly despite high levels of by-catch. Although modeling this movement would impact estimates of pup survival in the Hebrides, it would not impact the associated population estimates. There is also movement, across SMUs and countries, between the breeding and summer seasons. It is estimated that 200 grey seals spend the summer in the Netherlands (Brasseur et al. 2015), and telemetry data shows interchange of adults between the area covered by the population model and Ireland, Wales and continental Europe (Carter *et al.* submitted). Essentially, once the independent estimates have been scaled down to be comparable with pup production in regularly monitored colonies (Figure 1), we assume that the population associated with the independent estimate gives rise to that pup production. However, the any potential mismatch between the proportion of pup production and summer estimates included in the population model, is likely to have a negligible impact on the population estimates compared to other factors.

Acknowledgments

The report was based on data collected by numerous individuals. As well as published data (see References), data were provided by for SMUs 10 and 14 by Chichester Harbour Conservancy and Cumbria Wildlife Trust, respectively. For the use of unpublished Welsh data (Hilbre, Bardsey Island, Ramsey Island and Skomer MCZ), we would like to acknowledge the following individuals, and organizations: Jo Porter, Kate Lock, Lisa Morgan, Greg Morgan, Nathan Wilkie, Sylwia Zbijewska, Hilbre Bird Observatory, NRW, RSPB, The Wildlife Trust of South and West Wales.

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Special Areas of Conservation (SACs) for harbour seals in Scotland

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Abstract

All counts of harbour seals in the nine Special Areas of Conservation (SACs) for which they are a primary reason for selection or a qualifying feature (Sound of Barra) are presented for the period 1990 to 2019.

Both seal species appear to be doing well in Scotland overall and numbers have been increasing over the last few years. Although it is not possible to accurately calculate trends over short time periods using the approximately 5-yearly snapshots available for most areas, the duration of the long-term monitoring project allows us to identify overriding population trends and major short-term declines.

The time series of harbour seals counted within SACs compared with numbers found within a 50km range show that SACs are not reliable indicators of the wider population. This is especially evident for the Sound of Barra SAC, where harbour seal numbers have declined dramatically since the 1990s. In contrast, surrounding areas have seen a significant increase in numbers. To varying degrees, all SACs now represent a smaller proportion of the wider population than in the past.

Introduction

A detailed report of recent harbour seal surveys in Scotland and the counts and trends by region, Seal Management Unit (SMU), Special Areas of Conservation (SAC) and Sites of Special Scientific Interest is in final review and will be published shortly by Nature Scotland. For information, the results and trends for all seal SACs in Scotland are presented below.

In early 2005, eight SACs were designated for harbour seals in Scotland. Since then, the Sound of Barra, a Site of Community Importance, has been adopted by the European Commission, but it has not yet been formally designated as a SAC by the Scottish Government. For simplicity, it is included here with the original SACs that were designated in 2005.

Methods

Survey methods are described in detail in SCOS-BP 20/03.

Results

All Scottish SAC harbour seal counts are shown in Table 7 and plotted in Figure. Thompson *et al*. (2019) carried out a trend analyses for harbour seal SACs using data collected from 1990 to 2017. The new counts made in 2018 and 2019 are in line with the results from those analyses. No clear trend was found in four of the SACs (3 in West Scotland, 1 in Shetland). All other SACs have seen significant declines without subsequent recovery.

When the EU Habitats Directive was adopted in 1992, the total harbour seal count in all areas currently (in the process of being) designated as harbour seal SACs was over 6,000 (Table 7). This total was just over 2,000 in the most recent census (all SACs were last surveyed between 2017 and 2019). During the first full Scotland census in 1996-1997, over 20% of all harbour seals were counted within the current SACs. During the most recent census in 2016-2019, this proportion dropped to around 8%.

Trends observed for counts made within the boundaries of an SAC are not necessarily representative of the harbour seal numbers recorded within a wider area. Therefore, graphs provided in the following subsections present the SAC counts in the context of buffer areas, representing 10-50km at-sea distances from the SAC low water line, as well as in relation to the relevant Seal Management Area (subdivision). The buffer areas are shown on a map in Figure 1

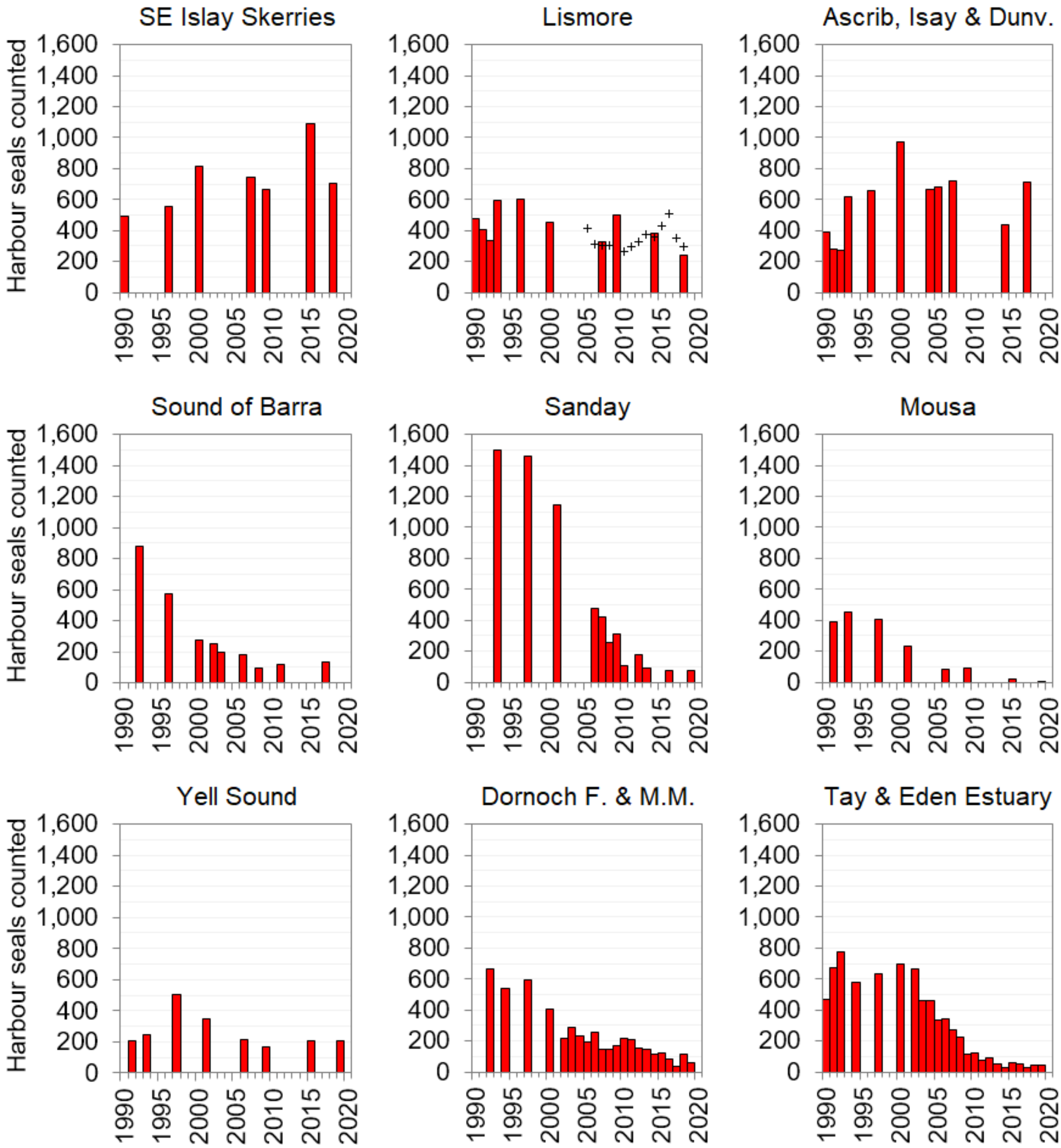

Figure1. August harbour seal counts in Special Areas of Conservation (SACs) for which harbour seals are a primary reason for selection or a qualifying feature (Sound of Barra). The black crosses in the Lismore plot indicate boat counts from surveys conducted by SNH.

Table 7. August counts of harbour seals in Special Areas of Conservation (SACs). The difference in fill-opacity reflects the size of a count relative to all SAC counts in the table.

Year	South-East Islay Skerries	Eileanan agus Sgeiran Lios mor	Ascrib, Isay and Dunvegan	Sound of Barra	Sanday	Mousa	Yell Sound Coast	Dornoch Firth and Morrich More	Firth of Tay and Eden Estuary	Most recent totals of all SACs combined	% of Scottish total
1990	493	476	393						467		
1991		405	278			388	210		670		
1992		337	272	878				662	773		
1993		596	618		1,498	455	245			6,218	
1994								542	575		
1995											
1996	552	603	656	576							
1997					1,458	402	501	593	633	5,974	20.2%
1998											
1999											
2000	812	453	968	276				405	700		
2001					1,148	235	351			5,348	
2002				249				220	668		
2003				201				290	461		
2004			664					231	459		
2005			678					191	335		
2006				179	478	83	212	257	342	3,494	14.9%
2007	741	325	719		425			144	275		
2008				92	260			145	222		
2009	666	498			308	93	168	166	111	2,821	13.8%
2010					107			219	124		
2011				116				208	77		
2012					180			157	88		
2013					92			143	50		
2014		380	434					111	29		
2015	1,087					23	205	120	60	2,517	9.9%
2016					72			85	51		
2017			712	132				39	29		
2018	706	238						117	40		
2019					77	7	209	62	41	2,184	8.1%

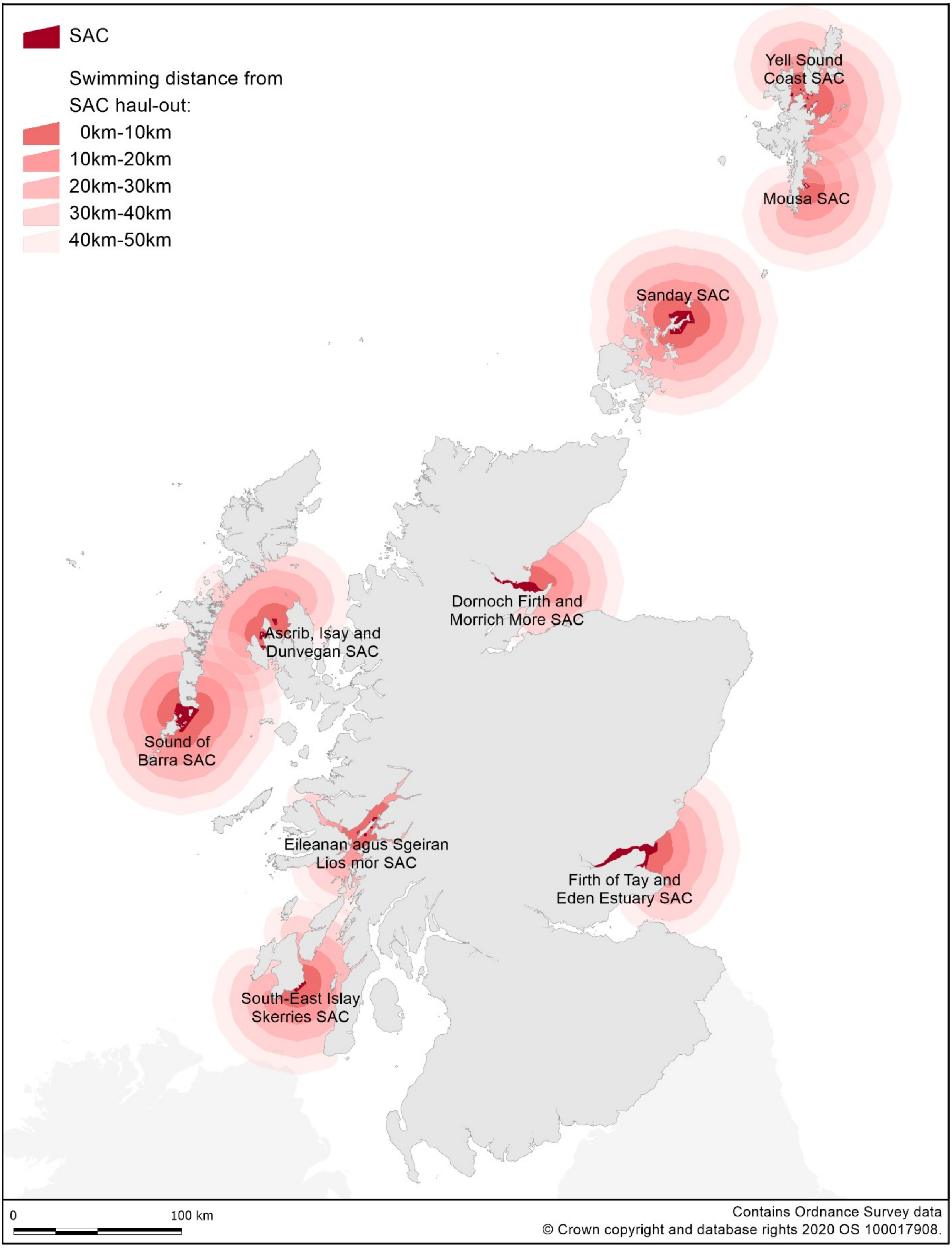

Figure 1. Map showing 10km wide buffer areas up to 50km around the nine harbour seal Special Areas of Conservation (SACs). These buffer areas are based on at-sea distances from intertidal areas within the SACs, and are used in Figure to Figure .

South-East Islay Skerries SAC

Harbour seals appear to be doing well in the South-East Islay Skerries SAC, even though the most recent 2018 count was 35% lower than the previous count in 2015 (Table 7). Remarkably, the SAC consistently contributed 34% to the 50km-buffer count in all four censuses between 1996 and 2015, before this proportion dropped to 27% in 2018 (Figure). The overall contribution to the West Scotland – South SMA subdivision also remained fairly stable between 10-14% throughout, suggesting that the SAC is a good indicator of overall harbour seal numbers found in this SMA subdivision. This may be due to the fact that there are no major haul-out sites within 10km swimming distance of the SAC, making it less likely for large groups of seals to switch from sites that lie inside the SAC to sites that are outside, and vice versa.

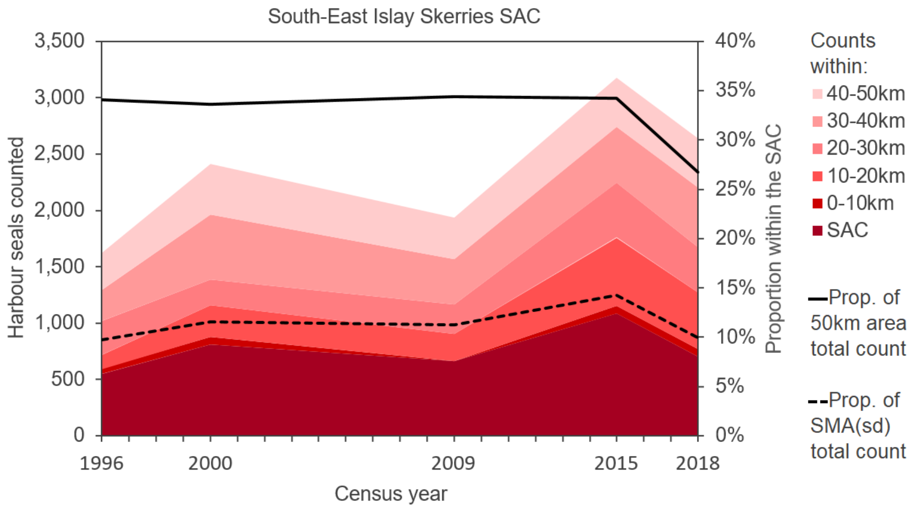

Figure 3. Harbour seal counts in the South-East Islay Skerries SAC and in 10km wide buffer areas extending up to 10, 20, 30, 40, and 50km from the SAC. The buffers are based on approximate swimming distances from the SAC and are shown in Figure 1. The solid black line shows the SAC count as a proportion of the 50km buffer count. The dotted black line shows the SAC count as a proportion of the total count for West Scotland - South.

Eileanan agus Sgeiran Lios mor SAC

Harbour seal numbers within the Eileanan agus Sgeiran Lios mor SAC have remained fairly stable. The counts produced by the aerial surveys may look like they represent a slow decline, but a relatively high count recorded during an SNH boat survey in 2016 suggests that this is due to natural variation (Figure). This can be expected, given that there are a number of other significant haul-out sites within 2-8km of the SAC. Indeed, the highest count for the wider area up to 50km from the SAC was recorded during the most recent survey in 2018 (Figure). The high potential for significant variations in the SAC count, due to the close proximity of other haul-out sites, and the fact that the proportion of the 50km-buffer count (and of the SMA subdivision total) recorded within the SAC has declined over time, suggest that the SAC is not necessarily a good indicator of seal numbers found over a wider area.

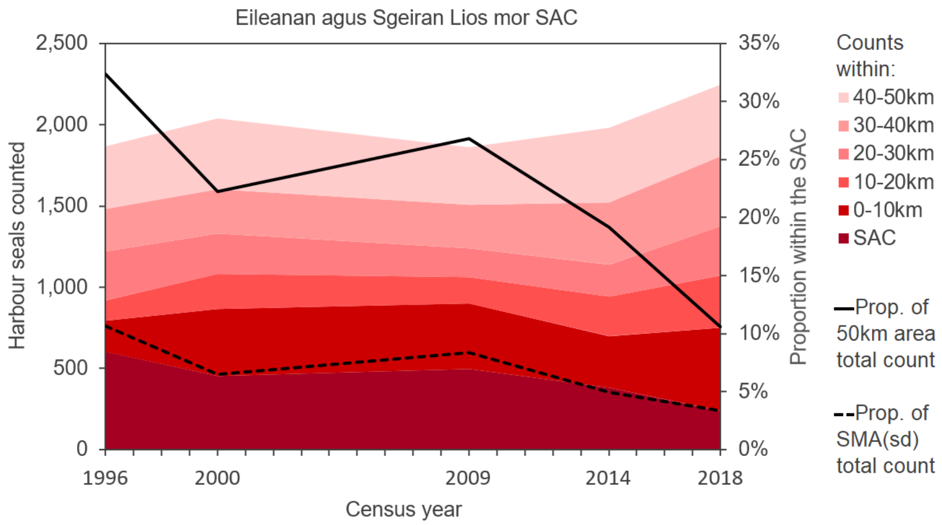

Figure 4. Harbour seal counts in the Eileanan agus Sgeiran Lios mor SAC and in 10km wide buffer areas extending up to 10, 20, 30, 40, and 50km from the SAC. The dotted black line shows the SAC count as a proportion of the total count for West Scotland – South. Other details as in Figure 3.

Ascrib, Isay and Dunvegan SAC

The harbour seal count in the Ascrib, Isay and Dunvegan SAC was close to 700 in four of the five censuses. The lower count in 2014 was compensated for by other haul-out sites in Loch Snizort that lie within 10km of the SAC (Figure). There are hardly any significant haul-out sites around 10-30km from the SAC. Just beyond that lie some of the high-density areas along the eastern coast of the Western Isles, and within 50km are the harbour seal hotspots to the east of Skye on North Rona and Raasay. The fairly consistent counts recorded within the SAC are not representative of the large increase observed in the West Scotland – Central SMA subdivision as a whole, where the count increased from 2,700 in 1996 to over 7,400 in 2017.

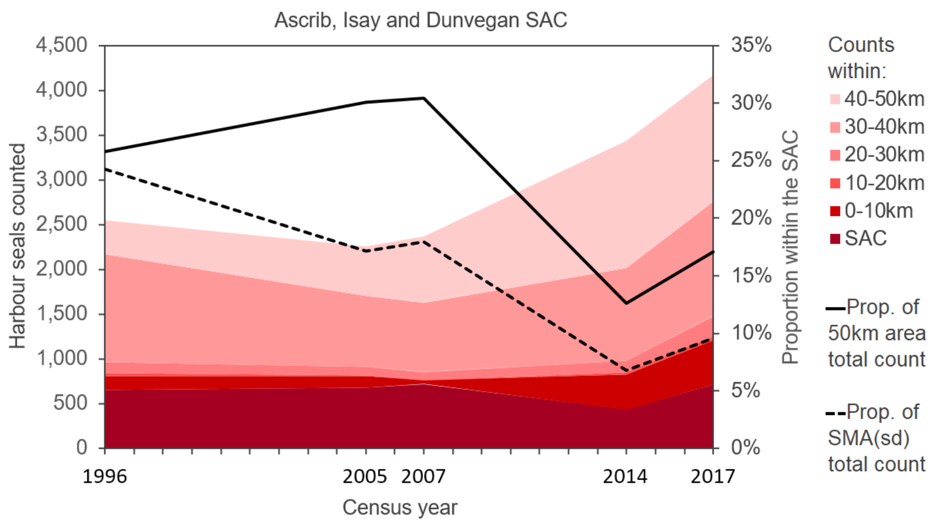

Figure 5. *Harbour seal counts in the Ascrib, Isay and Dunvegan SAC and in 10km wide buffer areas extending up to 10, 20, 30, 40, and 50km from the SAC. The dotted black line shows the SAC count as a proportion of the total count for West Scotland - Central. Other details as in Figure 3.*

Sound of Barra SAC

In 1992, 38% of all harbour seals counted in the Western Isles were recorded inside the boundaries of the Sound of Barra SAC. Over the next 16 years numbers decreased and, since 2008, the SAC has contributed 5% or less to the SMA total (Figure). The SAC count is even less representative of the 50km-buffer count which has increased significantly over the last ten years.

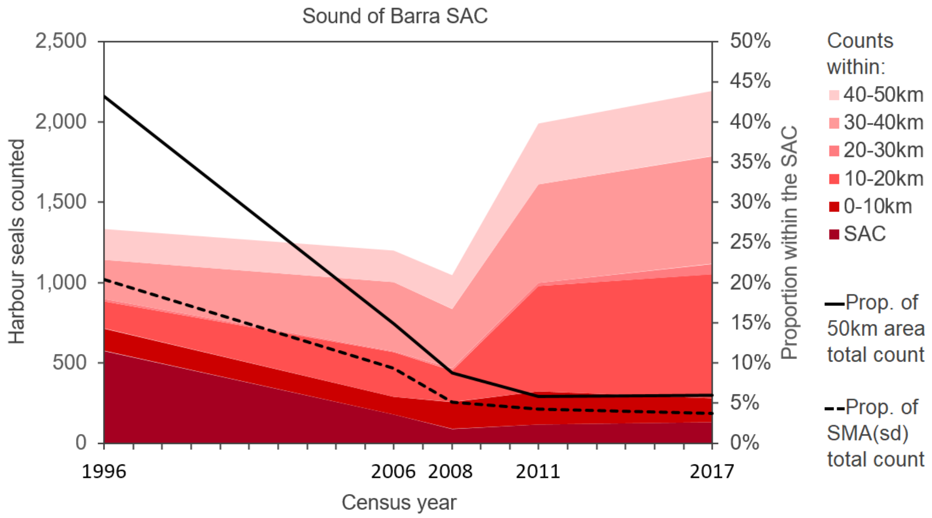

Figure 6. *Harbour seal counts in the Sound of Barra SAC and in 10km wide buffer areas extending up to 10, 20, 30, 40, and 50km from the SAC. The dotted black line shows the SAC count as a proportion of the total count for Western Isles. Other details as in Figure 3.*

Sanday SAC

In the 1990s, approximately 1,500 harbour seals were counted within the Sanday SAC, contributing 5% to the Scotland total during the first full census in 1996-1997. Since then, the SAC count has declined by 95%, even more dramatically than the Orkney total count, to which it now contributes only around 5% (Figure 7). This means that the Sanday SAC is one of the local areas hit hardest by the harbour seal decline observed in northern and eastern areas of Scotland.

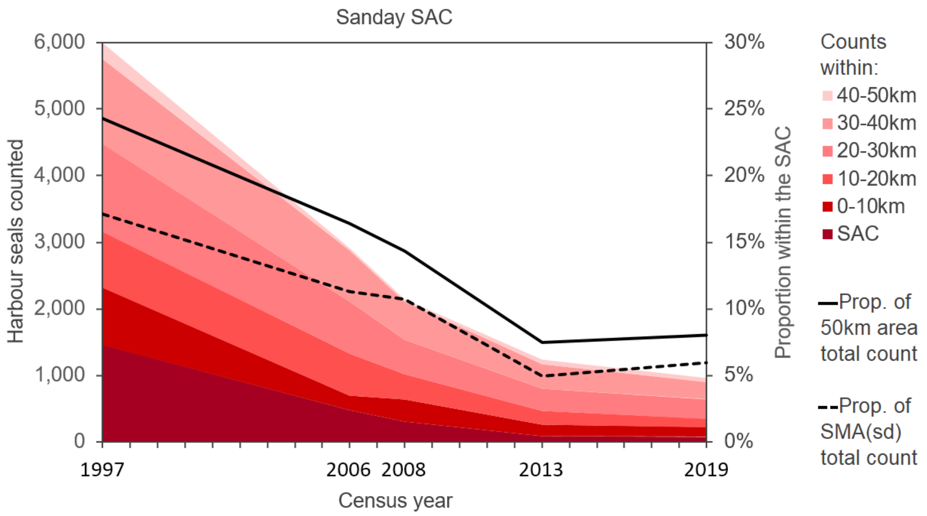

Figure 7. *Harbour seal counts in the Sanday SAC and in 10km wide buffer areas extending up to 10, 20, 30, 40, and 50km from the SAC. The dotted black line shows the SAC count as a proportion of the total count for Orkney. Other details as in Figure 3.*

Mousa SAC

Between 1997 and 2006 the harbour seal count for Shetland decreased by 50%, and subsequently remained stable. The count for the 50km-buffer area around the Mousa SAC followed a similar pattern up until 2009 and contributed around 40% to the Shetland count during this time. Over the last 10 years, numbers within the SAC and up to around 20km from the SAC have continued to decline, a trend which has not been observed in other parts of Shetland (Figure).

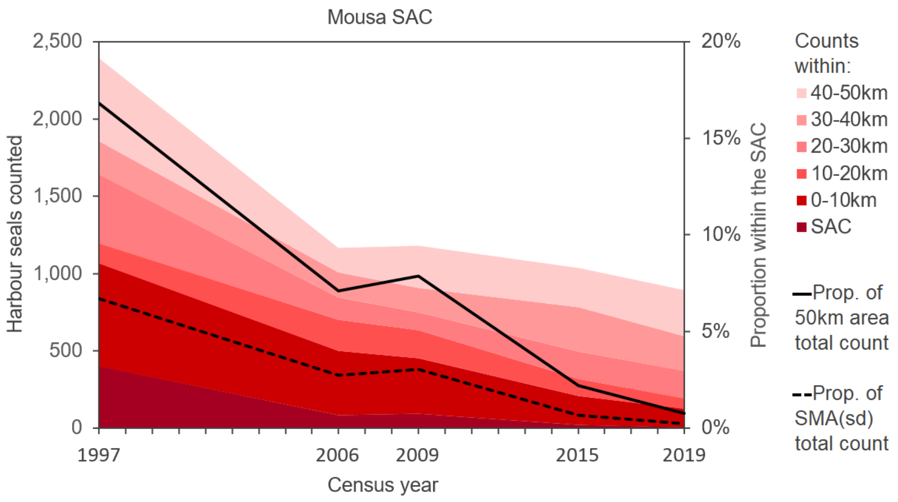

Figure 8. *Harbour seal counts in the Mousa SAC and in 10km wide buffer areas extending up to 10, 20, 30, 40, and 50km from the SAC. The dotted black line shows the SAC count as a proportion of the total count for Shetland. Other details as in Figure 3.*

Yell Sound Coast SAC

The Yell Sound SAC is just over 50km swimming distance to the north of the Mousa SAC, so large parts of the two 50km-buffer areas overlap. However, the Yell Sound SAC count has closely followed the trends observed over the wider area and in Shetland as a whole. During all five census counts, this SAC contributed 10-13% to the 50km-buffer area count and 6-8% to the Shetland total (Figure). This consistency is slightly surprising, given that there are several significant haul-out sites within 5km of the SAC, so that one might expect the numbers within the SAC to fluctuate quite considerably.

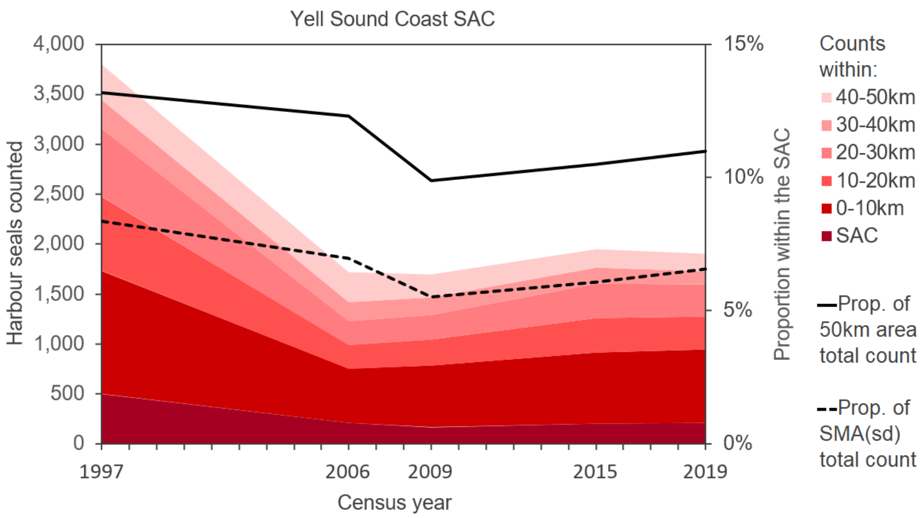

Figure 9. *Harbour seal counts in the Yell Sound Coast SAC and in 10km wide buffer areas extending up to 10, 20, 30, 40, and 50km from the SAC. The dotted black line shows the SAC count as a proportion of the total count for Shetland. Other details as in Figure 3.*

Dornoch Firth and Morrich More SAC

The harbour seal count for the Dornoch Firth and Morrich More SAC has declined continuously since the 1990s. This is neither representative of the wider area defined by the 50km-buffer area or of the Moray Firth SMA (Figure). Especially the establishment of Culbin Sands, just over 30km from the SAC, as the main harbour seal haul-out area in the Moray Firth, has compensated for the decrease of numbers found in the SAC. The proportion that the SAC contributes to the SMA total has decreased from 42% in 1997 to 6% in 2019.

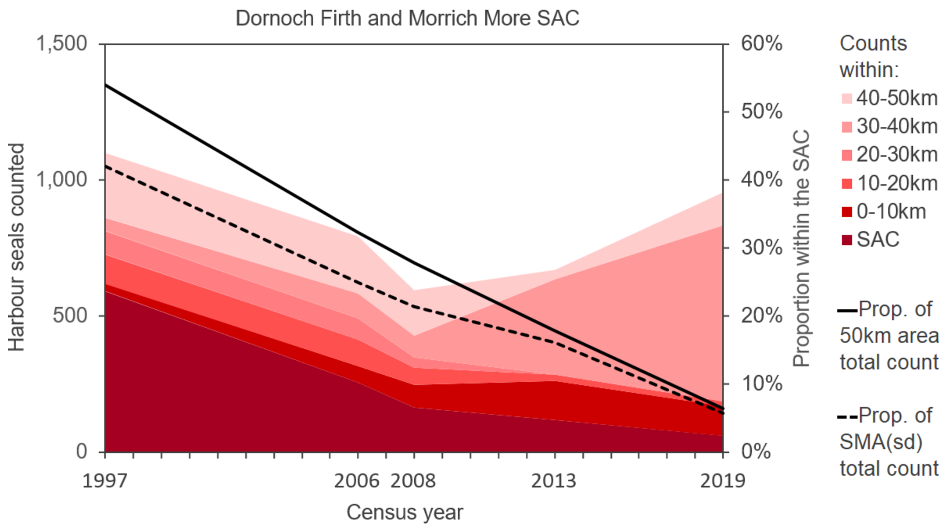

Figure 10. *Harbour seal counts in the Dornoch Firth and Morrich More SAC and in 10km wide buffer areas extending up to 10, 20, 30, 40, and 50km from the SAC. The dotted black line shows the SAC count as a proportion of the total count for Moray Firth. Other details as in Figure 3.*

Firth of Tay and Eden Estuary SAC

An even greater decline in harbour seal numbers has been recorded in the second harbour seal SAC along the eastern coast of Scotland, the Firth of Tay and Eden Estuary SAC. Small groups of animals that still use the SAC to haul out, are mainly found in the Firth of Tay upstream of the road bridge (Hanson *et al.* 2017). This is the most isolated harbour seal SAC in Scotland in terms of connectivity to other haul-out areas. Whereas there are a few more haul-out sites in the Firth of Forth, 40-90km from the SAC, the nearest large aggregation of harbour seals is at Findhorn and Culbin in the Moray Firth, over 260km away. Sites in East Scotland, which are not inside the SAC, have not seen the same declines as the SAC. Although numbers of harbour seals were never very high at these sites, counts have either remained stable or increased slightly. During the first census in 1996-1997, the SAC count represented 83% of the SMA total. Since then, this has decreased to 12% (Figure). Seal tracking data (SMRU unpublished data) does show interchange between the SAC sites and haulout sites in the Firth of Forth.

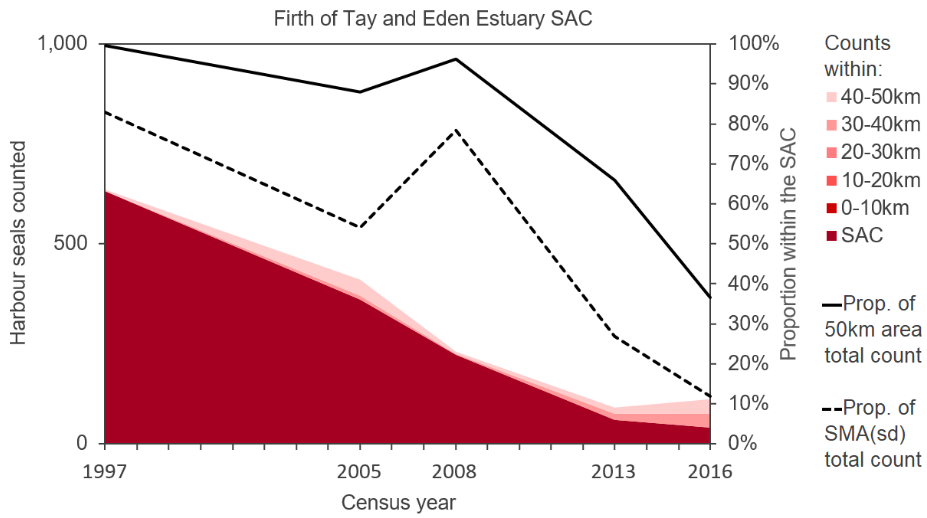

Figure 11. *Harbour seal counts in the Firth of Tay and Eden Estuary SAC and in 10km wide buffer areas extending up to 10, 20, 30, 40, and 50km from the SAC. The dotted black line shows the SAC count as a proportion of the total count for East Scotland. Other details as in Figure 3.*

Discussion

Harbour seals

During their recent examination of the status of harbour seals in the UK, Thompson *et al*. (2019) used count data collected up until August 2017 to analyse harbour seal abundance trends within Scottish Seal Management Areas (SMAs) and Special Areas of Conservation (SACs). Additional data from surveys, conducted in 2018 and 2019, confirm the trends and conclusions presented during that investigation.

Counts of seals on shore represent a proportion of the total population, as not all animals are ever hauled out at the same time. There is not a lot of data available to calculate this proportion during the harbour seal moult season when abundance surveys are conducted. It isn't possible to use data from the majority of telemetry tags deployed on animals, as the most common tags are glued to the fur and fall off when animals begin to moult. The only study conducted in the UK to estimate the proportion of harbour seals available to count during the aerial surveys was presented by Lonergan *et al*. (2013). Flipper tag data from 10 seals tagged in West Scotland and 15 seals tagged in Orkney were used to estimate a proportion of 0.72 (95% CI: 0.54–0.88). This is within the range of estimates (0.65-0.81) produced by studies carried out in Alaska and in California using VHF radio tags (Harvey & Goley, 2011; Simpkins *et al*., 2003).

Changes in the age structure or in the sex ratio over time can affect whether or not a consistent subset of the population is being counted from year to year. All individual seals hauled out during the August surveys are included in the count, independent of which age class they belong to. Because the harbour seal moult season closely follows the harbour seal pupping season, some of the animals counted will be recently born pups. These weaned pups can look very similar to yearlings making it impossible to distinguish them when counting from aerial photographs (Thompson & Rothery, 1987). Harbour seal pups often disperse after leaving their mothers and probably don't haul out as much as older animals that need to moult in August. Therefore, it is assumed that the number of pups counted during the moult surveys is negligible (Thompson & Harwood, 1990). It is not known whether the proportion of pups found on haul-out sites decreases throughout August. In addition, one would expect to find a higher proportion of pups counted in regions where populations are increasing, i.e. where fecundity is higher and/or pre-weaning pup mortality is lower. An increase in the relative number of pups could lead to a small overestimate of the rate of increase calculated for a population based on the count data.

It is possible that the timing of the moult season can change over several years, or that the timing may vary regionally, resulting in different proportions available to count. This could make it even harder to identify long-term trends or to precisely estimate total population size. However, there are no data to suggest that this is the case in Scotland.

Harbour seal SACs generally don't appear to be reliable indicators of wider populations. This is especially evident for the Sound of Barra SAC, where harbour seal numbers have declined dramatically since the 1990s. In contrast, surrounding areas have seen a significant increase in numbers. To varying degrees, all SACs now represent a smaller proportion of the wider population than in the past. This consistency seems rather odd, and it is not known why this is the case. Because these protection areas were selected based on high counts, it may be that these areas were closer to a maximum capacity at the time and numbers were always more likely to decline at higher rates compared to areas with lower densities. It makes sense that a small area with a high density of animals is more likely to see a decline in numbers than further increases.

Grey seals

The summer counts suggest that the grey seal population has increased over the last 20 years without any regional declines as observed for harbour seals. This is consistent with grey seal pup production estimates. Over the last 20 years, the summer haul-out counts of grey seals in eastern England have been growing at a similar rate of approximately 16% p.a. to the pup production in the SMU. Whereas the large number of harbour seals found in the southern North Sea belong to a genetically different metapopulation compared to animals in Scotland (Olsen *et al.*, 2017), this is not the case for grey seals that can travel great distances during foraging trips or between foraging and breeding regions (Russell *et al.*, 2013), so that large changes in one region are more likely to affect numbers in another.

Conclusions

Both seal species appear to be doing well in Scotland overall and numbers have been increasing over the last few years. The main difference lies in the fact that there are clear differences in regional population trends for harbour seals. Eastern and northern areas that have seen large declines in the numbers of harbour seals counted since ca. 2000 have shown no sign of recovery. Although it is not possible to accurately calculate trends over short time periods using the approximately 5-yearly snapshots available for most areas, the duration of the long-term monitoring project allows us to identify overriding population trends and major short-term declines. The time series of harbour seals counted within Special Areas of Conservation (SACs) compared with numbers found within 50km of an SAC show that it is not possible to use the existing SACs as indicator sites for the wider population. Seals are highly mobile, and comprehensive surveys are necessary in order to understand whether or not harbour seal populations are likely to be stable, increasing, or declining.

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Harbour seal decline – vital rates and drivers: summary of outputs 2015-2020

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Abstract

Numbers of harbour seals (*Phoca vitulina*) have dramatically declined in parts of Scotland over the last 20 years. This report provides a summary of the most relevant outputs from the 'harbour seal decline – vital rates and drivers' task (Marine Mammal Scientific Support Research Programme MMSS/02/15), which aims to identify, understand and assess the relative contribution of various factors in this decline.

1. A simulation tool was developed to include a population model to simulate data and a model-fitting step to recover parameters used in the simulation. Simulations were used to investigate the fit of the population model to moult only data and sparse data-series. Harbour seal demographic parameters from an expert elicitation were used to conduct further simulations of population trends given different sets of vital rates. **Simulations demonstrated that while decreases in pup survival, juvenile survival and fecundity may contribute to a population decline of the magnitude observed in Orkney, there must be a decrease in adult survival.**

2. Photo-identification data on harbour seals were collected during the breeding seasons of 2016 to 2019 in Orkney, Kintyre and Isle of Skye to generate sighting and reproductive histories of harbour seals for the estimation of survival and fecundity rates. **Orkney had the lowest number of identified seals of all sites, as well as a declining number of identified mother-pup pairs**.

3. Pregnancy status was estimated from concentrations of progesterone in blubber and blood for female harbour seals captured in the Moray Firth, North Coast and Orkney and West Scotland. **The proportion of females classed as pregnant was high in all regions (63%-100%) with no statistically significant differences, although sample sizes were small.**

4. Health and nutritional status of harbour seals from Orkney and North Coast, and from the Isle of Skye were investigated. Age, morphometric data, urinary domoic acid (DA) concentrations, serum clinical chemistry profiles and serum fatty acid (FA) signatures were analysed. There were no differences in age ranges, the average age of seals caught, or body condition between the two study populations. **Analysis of urine samples showed higher DA concentrations measured in the Orkney and North Coast samples**. **Serum FA analysis indicated that the diets of seals from both areas were not significantly different although the results were confounded by season.**

5. The concentrations of DA and paralytic shellfish toxins (PSTs) were measured in 42 different fish species caught in Scotland between 2012 and 2019. **Results so far suggest that fish had higher concentrations of DA compared to PSTs with a peak in the summer / autumn months**. **The highest DA concentrations were measured along the East coast of Scotland and in Orkney.**

6. A risk assessment model was developed to estimate the risk of toxicity from the harmful algae bloom (HAB) toxins to Scottish harbour seal populations, through the ingestion of contaminated prey, simulating risks to adult and juvenile harbour seals separately. The results were highly dependent on toxin type, its persistence and the animals' foraging regime as well as age class, all of which affected the proportion of exposed animals exceeding the thresholds. **PSTs and okadaic acid (OA) exposure was unlikely to result in mortalities. However, DA exposure resulted in doses**

above an estimated lethal threshold with approximately 17% of exposed juveniles and 5% of adults ingesting doses above this threshold, causing mortality. These results are also on the conservative side as further investigation is indicating that the assay to measure DA is underestimating the concentrations in the fish due to the complex nature of the fish tissues and because our fish samples were not collected during periods of toxic bloom events and thus represent minimum doses. Further work to address these issues is ongoing.

7. A pilot study was conducted in August 2019 in Orkney to assess the feasibility of passive acoustic monitoring to monitor predator-prey interactions between killer whales and harbour seals. **The preliminary acoustic analysis demonstrates the feasibility of passive acoustic monitoring of killer whales in coastal areas of Scotland, and work is ongoing to improve the species identification of the automated detection algorithm.**

Introduction

A decline in the abundance of Scottish harbour seals (*Phoca vitulina*), first detected in the early 2000s (Lonergan et al. 2007), has continued in some of the surveyed regions, with the decline in numbers being more apparent on the east and north coasts of Scotland and in the Northern Isles (SCOS 2019). In order to determine the management and mitigation options to address this situation, the relative contribution of various factors potentially involved need to be identified, understood and assessed. While causal mechanisms of the harbour seal decline have not been identified, several factors have been excluded as primary causes of the decline, although may remain as potential secondary causes. Potential drivers that require further research include changes in prey quality and/or availability, competition with grey seals for prey resources, predation (by grey seals and by killer whales), and the exposure of seals to toxins from harmful algae (SCOS 2019).

Irrespective of the factor or factors driving the decline, changes observed at the population level must originate from changes in vital rates (i.e. survival and fecundity rates). Therefore, it is fundamental to obtain information on such life history parameters from long-term studies (e.g. Bowen et al. 2003) in regions with contrasting seal population trajectories (declining compared to stable or increasing populations). At present, life history information for harbour seals in Scotland is available only from Loch Fleet and the Moray Firth (Cordes and Thompson 2014; Graham et al. 2017), but is lacking for other regions in Scotland. Recognising differences in such population parameters and their drivers between regions of contrasting population trajectories can help determine how and where the potentially important natural and/or anthropogenic factors are acting. In complex ecosystems, populations may experience pressure from multiple causes (e.g. food shortage, predation, toxin exposure and anthropogenic mortality). Causes of mortality or poor condition may impact different parts of the population in different ways (e.g. young or pregnant animals might be especially vulnerable to nutritional stress). Also, for long-lived animals such as harbour seals, considerable time lags may be seen between cause and consequence in terms of population numbers. Hence the outcomes of combined effects at the level of population abundance may be difficult to predict intuitively.

This paper presents a summary of the main research outputs on the task ‘harbour seal decline – vital rates and drivers’ under the Marine Mammal Scientific Support Research Programme MMSS/02/15 (Phase II) to inform SCOS. The outputs are classified into four of the main approaches to the task. The summarized outputs are from currently published or in prep peer-reviewed papers and reports, while some of the work is ongoing.

Methods

1. Integrated population model

The objective is to develop an integrated population model (IPM) for harbour seals that incorporates count data from visual aerial surveys and photographic mark-recapture data. This will be a state-space model with an underlying population process model and submodels for each observation process. The IPM will be fitted in a Bayesian framework and the results used to investigate potential drivers of observed population trends at each site. To date, work has focused on the development of a suitable population process model and on determining appropriate prior distributions for life-history parameters.

First, a population model was developed based on the original and subsequent developments of the Moray Firth population dynamics model (Caillat et al. 2019; Matthiopoulos et al. 2014) and was used to investigate whether it could be fit to moult count only data and to sparse data-series. The model-fitting process included an age-structured population model to produce simulated data, and a model-fitting step to recover the parameters used in the simulation (see Arso Civil et al. 2018 for full details)

Informative priors on population demographic parameters (e.g. survival and fecundity rates) can be used to restrict parameter ranges and to suggest to a population dynamics model the values considered to be most likely. After the initial development and testing of the population model, a review and expert elicitation of plausible ranges for harbour seal vital rates was undertaken. Details on the expert elicitation process, including the calculation of composite distributions for each of the vital rates of interest can be found in Arso Civil et al. (2019).

The median rates from the expert elicitation process were used to conduct further simulations of population trends given different sets of vital rates, as well as an analysis of population sensitivity to changes in individual vital rates. A population model based around an age and sex-segregated Leslie matrix model (Caswell 2001) was used for the simulations (see Approach 1 in Arso Civil et al. 2019 for details). The simulated population was designed to be similar to that of Scapa Flow (Orkney), with a starting population of 4,500 animals and a timespan of 35 years. The goal of this exercise was to identify, for each vital rate, the magnitude of reduction required to produce the observed decline in the simulated counts of hauled out animals. First, the simulation was run with default vital rates and compared the expected number of animals hauled out to the observed counts at Scapa Flow. Then, for each vital rate, reductions in that vital rate from 1-100% were simulated beginning at year 15 of the simulation run (coinciding with the time when the decline in harbour seal numbers was first detected (SCOS, 2019)), with all other vital rates remaining constant. The expected number of hauled out individuals was then compared to the observed number of hauled out individuals during aerial survey moult counts.

2. Photo-ID for vital rates estimation

Photo-identification data on harbour seals were collected during the breeding season (June and July) of 2016 to 2019 at three selected study sites of contrasting population trajectories: Orkney (declining site), Kintyre (stable or increasing site) and Isle of Skye (stable or increasing site). In Orkney and Kintyre, selected sites were visited at least once every three days before the birth of the first pup, and every day or every other day after that. Surveys started approximately one hour before low tide and lasted for 2 to 4 hours until all seals (including pups) had been photographed. Photographs of the head and neck area of each seal were taken via digi-scoping from a distance of

40 to 150 metres. In Isle of Skye, photo-identification data were collected from tourist boats departing Dunvegan Castle grounds, using a digital camera, three to four times per week. Photographs were graded for quality and seals identified from their unique pelage markings, using a computer-assisted pattern matching software (Wild-ID; Bolger et al. 2012) and manual matching. Efforts are ongoing to age seals to approximate age classes (yearling, juvenile, adult) for the estimation of survival and fecundity rates which focuses on adults. Seals are aged based on body size and shape, with reference from individuals followed though photo-ID since birth.

A mark-recapture modelling framework will be used to estimate vital rates. Apparent survival rates will be estimated for adults using open-population models, and sex-specific survival estimates will be derived using an open-population model conditioning release upon the identification of sex (Cordes and Thompson 2014). Fecundity rates will be estimated from reproductive histories of females using an open robust design multistate model accounting for uncertainty in breeding status (i.e. females seen without a pup cannot be classed with certainty as non-breeders) and seasonality (e.g. Cheney et al. 2019).

3. <u>Live capture-release at photo-ID sites</u>

3.1 Determining pregnancy status in harbour seals using progesterone concentrations

Pregnancy status in harbour seals was estimated from concentrations of progesterone in blubber and blood (serum) samples for female harbour seals captured and released at haulout sites in three of the Seal Management Areas; the Moray Firth, West Scotland and North Coast and Orkney. Full details on analysis of samples and model fitting can be found in Hall et al. (2020). Captures were conducted between February and May 2015-2018, before the breeding season (June and July in those areas). If possible, captures occurred at sites where photo-id would be collected during the following breeding season to increase the likelihood of determining reproductive outcome (pregnant or possibly non-pregnant) for some of the sampled mature females.

Blood samples were analysed using a commercially available progesterone ELISA (DRG International Inc, Springfield, USA). Steroid hormones were extracted from the blubber samples following the method of Kellar et al. (2006) and as applied to harbour seal samples by Kershaw and Hall (2016). Generalised linear models with a binomial family and logit link function were fitted to training (60% of the data) and test datasets (40% of the data) to estimate pregnancy status from progesterone concentrations in blubber, plasma or both, and a received operating curves approach was used to evaluate the performance of each classifier.

3.2 Health and nutritional markers in harbour seals from Scottish populations with differing population trajectories

Standard morphometric data (mass, girth, length) and sex were recorded for harbour seals caught in Orkney and Pentland Firth (n=90 between April 2016 and April 2018) and on the Isle of Skye (n=32, March 2017). In addition, serum and urine samples were collected and one incisor tooth was taken from a subset of these individuals for ageing (n = 61). Age data, morphometric data, urinary domoic acid (DA) concentrations, serum clinical chemistry profiles and serum fatty acid signatures were analysed to investigate the health and nutritional status of harbour seals between a declining (Orkney and North Coast Seal Management area) and a stable population (Isle of Skye, within West Scotland Seal Management area) (Kershaw et al. in prep-a).

Variation between the ages of seals caught in both study areas was investigated. Variation in overall body condition (calculated using morphometric indices to reflect nutritive condition quantified as the energy stores of an individual) was also investigated. Urine samples were analysed to assess exposure of seals from different areas to DA using Generalized Linear Models (GLMs) with a Gamma distribution and a log-link function. In order to investigate any perturbations in metabolic and physiological processes, a standard panel of clinical chemistry measurements were carried out including a range of electrolytes, minerals, hormones and enzymes, and their concentrations used for diagnostic purposes. Finally, serum fatty acid (FA) profiles were compared between the two study populations to investigate potential variation in seal diet. Although some metabolism of FAs takes place after ingestion, they are generally deposited and then released from adipose tissue with little modification, and in a predictable way such that specific profiles and combinations of FAs can be used to reflect predator diet.

4. Improving the understanding of potential drivers of population change

4.1 Toxins from harmful algae in fish from Scottish waters
For the first time, the concentrations of domoic acid (DA) and paralytic shellfish toxins (PSTs), two toxins of commercial and environmental importance, were measured in 42 different fish species caught in Scotland between February and November, 2012 - 2019. The aim was to investigate the potential routes of trophic transfer of toxins produced by HABS to top marine predators in Scottish waters through their prey. The viscera (digestive tracts) of fish were homogenised, and DA and PSTs were extracted and quantified using commercially available Enzyme Linked Immunosorbent Assays (ELISAs) used for shellfish samples. Method development and optimisation to confirm the use of these ELISAs for toxin quantification in fish samples is still ongoing with colleagues at CEFAS who are also processing a subset of the samples to quantify these two toxins using Liquid Chromatography-Mass Spectrometry methods.

Toxin data were analysed to investigate variation in measured concentrations by species, season and sampling locations around Scotland using GLMs. Seasonality was incorporated into the DA analysis (as samples collected throughout the year were processed) using a parametric seasonal model called the '*cosinor*' model which is based on a sinusoidal pattern. Only samples collected in June and August were analysed for PSTs, so seasonality was not included in the final model for PSTs.

4.2 Estimating the risk of exposure to harmful algal toxins among Scottish harbour seals
A risk assessment model was developed to estimate the risk of toxicity from the HAB toxins to Scottish harbour seal populations through the ingestion of contaminated prey. First, samples of fish collected from Orkney, Shetland and the Firth of Forth between 2010 and 2019 were analysed for the presence of domoic acid (DA), paralytic shellfish toxin (PST) and okadaic acid (OA). The analytical methods and detailed results are given in Jensen et al. (2015) and Kershaw et al. (in prep-b), respectively. The model incorporated information on the concentrations of the three major HAB toxins found in seal prey around Scotland, the seasonal persistence of the toxins in the fish, the foraging patterns and daily energy requirements of harbour seals, and three different estimated toxicity thresholds (based on those published for other mammals and humans) for each of the toxins: a no observable adverse effect level (NOAEL), a lowest observable adverse effect level (LOAEL), and a neurotoxic dose (ND) or lethal dose sufficient to kill 50% of the animals (LDL). Simulations were carried out separately for adult and juvenile harbour seals, and the resulting annual mortality for the higher thresholds, or likelihood that animals would experience adverse health effects for the lower thresholds, was calculated. Model parameters and simulation steps are detailed in Hall et al. (in prep).

4.3 Passive acoustic monitoring (PAM) of killer whales in Scapa Flow, Orkney
A pilot study was undertaken in 2019 in Scapa Flow (Orkney) to assess the feasibility of PAM to monitor predator-prey interactions in coastal areas of Scotland, to ultimately inform the predator presence and potential impact of killer whales on harbour seals (Isojunno and Gkikopoulou 2020). One acoustic recorder (Loggerhead Instruments) was deployed and successfully recovered on the

Flotta Grinds navigation buoy (58.8483, -3.0013) in Scapa Flow from 12 July to 25 August 2019, resulting in thirty-one days of acoustic data. Automated detectors were applied and customised in Pamguard Beta 2.01.03 (Gillespie et al. 2008) to detect killer whale vocalizations. Separate automated detectors were developed for killer whale whistles, clicks and pulsed calls respectively. The performance of the detectors, including both false positive and false negative rates, was assessed by listening to sub-sections of the dataset. The recordings were also compared to recordings from two locations in the Minch, west of Scotland, collected as part of the COMPASS project (https://compass-oceanscience.eu/) in 2018 to provide useful comparison for noise levels as well as potential predator presence.

Results and Discussion

1. Integrated population model

The initial population model performed well using simulated data when only moult counts were available; satisfactory performance was also achieved when some years were removed from the data, leaving intermittent moult counts similar to the true observational data set (e.g. Caillat et al. 2019) (Figure 1). When applied to real count data from Orkney, the model was also able to capture the change-point year with reasonable certainty despite the sparse data (Figure 2). See Arso Civil et al. (2018) for full details.

Table 1 shows the resulting composite distributions from the expert elicitation process, reflecting the most plausible limits and distributions for the true values. Simulations based on these vital rates were in agreement with the aerial survey moult counts for the first ~15 years of data for Scapa Flow (Orkney), but were not consistent with the low counts on the second part of the time series (during the decline). Decreasing pup survival, juvenile survival or fecundity from year 15 onwards resulted in a decline of the simulated population, but not of the same magnitude as the observed decline (Figure 3 A-C). Even a 100% reduction in these parameters beginning at year 15 would be insufficient to explain the observed decrease in the population. However, the simulation was very sensitive to decreases in adult (male and female) survival (Figure 3-D). A 10-11% reduction in adult survival from year 15 onwards would be sufficient to explain the observed decline. In summary, this simulation exercise demonstrates that while decreases in pup survival, juvenile survival, or fecundity may contribute to a population decline of the magnitude observed at Scapa Flow, there must have been a decrease in adult survival.

2. Photo-ID for vital rates estimation

The number of seals identified varied per study area and year. Orkney had the lowest number of identified seals of all sites, declining every year from 124 seals in 2016 to 97 seals in 2019, and had a declining number of identified mother-pup pairs, from 43 to 29 over the study period. Kintyre had a higher number of identified seals per year (ranging from 132 to 186 seals in different years) , although the number of mother-pup pairs was proportionately very low (21 to 24), most likely because some identified females used different (non-monitored) haulout sites to give birth and one of the monitored sites seemed to be primarily used by males. Isle of Skye had the largest number of seals identified every year (ranging from 283 to 486 in different years between 2016 and 2018; processing of 2019 photo-identification data is ongoing), with 61 to 79 mother-pup pairs identified annually. The photo-identification data collected in Kintyre and Orkney resulted in similar sized catalogues of individual seals, with <250 adult (i.e. non-pup) seals identified in Kintyre and <200 seals in Orkney. Isle of Skye has the largest catalogue with >500 seals identified.

3. Live capture-release at the photo-ID sites

3.1 Determining pregnancy status in harbour seals using progesterone concentrations

Plasma and blubber samples were obtained for 103 and 79 out of the 104 captured females, respectively. Of the sampled females, the reproductive status of 51 was subsequently observed during the breeding season and classed as 'pregnant' (observed pregnant and/or with pup, n=29) or presumed 'non-pregnant' (n=22). For these, progesterone concentrations in plasma were available for all animals (n=51) and blubber concentrations were available for 41 animals.

The accuracy of the models to predict pregnancy status was 85% for plasma concentrations, 77% for the blubber concentrations and 87.5% for the combined analysis (both blubber and plasma). Based on these models and the estimated cut-point (threshold) to determine pregnancy, the proportion of animals categorised as pregnant was high in all regions (63% - 100% depending on the matrix used, i.e. plasma, blubber or plasma and blubber combined). Proportions were highest in the mature females from Isle of Skye using either plasma or blubber diagnostic approaches. Sample sizes were, however, small and hence observed differences in proportions between sites were not statistically significant.

3.2 Health and nutritional markers in harbour seals from Scottish populations with differing population trajectories

There were no differences observed in the age ranges, or average age of seals caught in the two study populations, with average ages of 9.9 ± 5.2 years and 9.5 ± 4.5 years for the West Scotland, and Orkney and North Coast populations, respectively (one-way ANOVA; $p = 0.2$, df =1, $F = 1.67$). Seals from West Scotland had significantly higher girth/length ratios that those from Orkney and North Coast (one-way ANOVA; $p = 0.005$, df = 1, $F = 8.16$), but their mass/length ratios were not significantly different. The body condition of individuals is expected to vary seasonally, with animals accumulating energy reserves in the spring and early summer in the build up to the breeding season in June/July. Time of year can thus bias the body condition estimates if individuals were not measured during the same period of their annual life cycle. This was the case in this dataset where many of the females were pregnant but sampling on the West Coast occurred slightly earlier (Hall, et al. 2020). However, even when the sampling time of year bias is considered, whereby the Orkney and North Coast seals were sampled in the build up to the breeding season, they were not in significantly better condition than the West Scotland animals using the mass/length metric. Thus, we found no evidence that seals in the declining population in Orkney and the North Coast are unable to accrue the same energy reserves as those in a stable population.

Analysis of urine samples showed that harbour seals in both the stable and declining population are exposed to DA with concentrations ranging from 190 to 16,4991 pg/ml, likely from recent exposure. Higher levels of DA were measured in the urine of Orkney and North Coast harbour seals (GLM; $p < 0.001$), which could potentially put them more at risk of neurotoxic effects than the seals from the stable West Scotland population. Further studies are ongoing to determine the importance of DA ingestion on the population dynamics of Scottish harbour seals in terms of modelling toxic thresholds and risks of exposure (see sections 4.1 and 4.2).

Regarding serum clinical chemistry parameters comparison, there were lower circulating concentrations of an enzyme involved in protein metabolism (alanine aminotransferase) (one way ANOVA; $p = 0.005$, df = 1, $F = 8.25$) and total protein (one-way ANOVA; $p = 0.0008$, df = 1, $F = 12.0$) in Orkney and North Coast seals which may suggest that they were in a more "fasting associated" metabolic state than seals from the West Scotland population. There was no clear clustering of serum FAs by region indicating that the diets of the sampled seals were likely not significantly different in West Scotland compared to the declining population in Orkney and North Coast (Figure 4). However, there was clustering of a particular class of FA called dimethyl acetals that are commonly used as an indicator of plasmalogen levels which have multiple cellular functions, notably as important antioxidants. Differences in this lipid class between the two populations are hard to interpret because of the multi-functional nature of these lipids and the absence of baseline data for harbour seals.

4. Improving the understanding of potential drivers of population change

4.1 Toxins from harmful algae in fish from Scottish waters

Results so far suggest that fish had higher mean concentrations of DA (0.11 ± 0.52 ug/g) compared to PSTs (0.031 ± 0.04 ug/g). DA concentrations were measured over the year from February to November, with a peak in the summer / autumn months (*cosinor* GLM; significant seasonality based on adjusted significance level of 0.025) (Fig. 5a). The highest DA concentrations were measured along the East coast of Scotland and in Orkney (GLM; p values < 0.01) (Fig. 5b). Whole fish DA concentrations were highest in pelagic species including mackerel and herring (GLM; p values = 0.05) (Fig. 5c), key forage fish for marine predators including seals, cetaceans and seabirds. PSTs showed highest concentrations in June compared to August (GLM; p = 0.001), consistent with phytoplankton bloom timings. The detection of both toxins in such a range of demersal, pelagic and benthic fish prey species suggests that both the fish, and by extension, piscivorous marine predators, experience multiple routes of toxin exposure (Kershaw et al. in prep-b). Risk assessment models to understand the impacts of exposure to HAB toxins on marine predators therefore need to consider how chronic, low-dose exposure as well as acute exposure during a bloom could lead to mortalities. As such, these data will provide an indication of the range and variability of toxin uptake by fish with different ecological niches and will facilitate predator risk assessments, allowing exposure scenarios to be based on empirical data (Hall et al. in prep).

4.2 Estimating the risk of exposure to harmful algal toxins among Scottish harbour seals

The results from the simulations were highly dependent on toxin type, seasonal persistence and foraging regime as well as age class, all of which affected the proportion of exposed animals exceeding the thresholds. PST and OA exposure were unlikely to result in seal mortalities. However, exposure to DA was lethal and resulted in animals exceeding the neurotoxic dose threshold. Simulations suggested that in general juveniles are more at risk than adults (Figure 6) due to their higher mass-specific energetic demands. Up to 16.6% of exposed juveniles and 4.5% of exposed adults exceeded the lethal threshold.

Because the method development and optimisation on the use of ELISAs for toxin quantification in fish samples is still ongoing (see section 4.1), results on the proportion of animals exceeding toxicity thresholds may increase as the ELISAs appear to be considerably underestimating the concentration of DA (compared to chromatographic methods used by Cefas to analyse DA in shellfish for human consumption). In addition, the model does not include samples of fish prey collected during bloom 'events', i.e. large toxic blooms resulting in shellfish fishery and harvesting area closures. Thus, the simulations suggest that DA exposure remains a potential factor involved in the regional decline of harbour seals in areas of Scotland.

4.3 Passive acoustic monitoring of killer whales in Scapa Flow, Orkney

Delphinid whistles were recorded in all three datasets, and killer whale vocalizations were positively identified on 12 and 13 July in the data from the recorder deployed on the Flotta Grinds navigation buoy in Scapa Flow; some of these detections coincided with sightings in the area. So far, few harbour or grey seal vocalizations have been detected, though further auditing work is on-going. As expected, the killer whale detections included both false positives and false negatives. Compared to the COMPASS recordings, false positives were more common in the Scapa Flow dataset, partly due to the frequent presence of vessels in the area and the nature of the mooring (shallow water and tidal water movement).

The preliminary acoustic analysis of the three different datasets demonstrates feasibility of passive acoustic monitoring of killer whales in coastal areas of Scotland, although caveats must be considered when interpreting acoustic detections of killer whales. These include likely variation in call rates with killer whale behavioural state, effect of ambient noise in detection probability and potential for species misidentification. Analysis work is ongoing to improve the species identification of the killer whale detection algorithm, as well as to increase effort to detect seal vocalizations from the recordings; automated methods were not developed for seal vocalizations during this pilot study.

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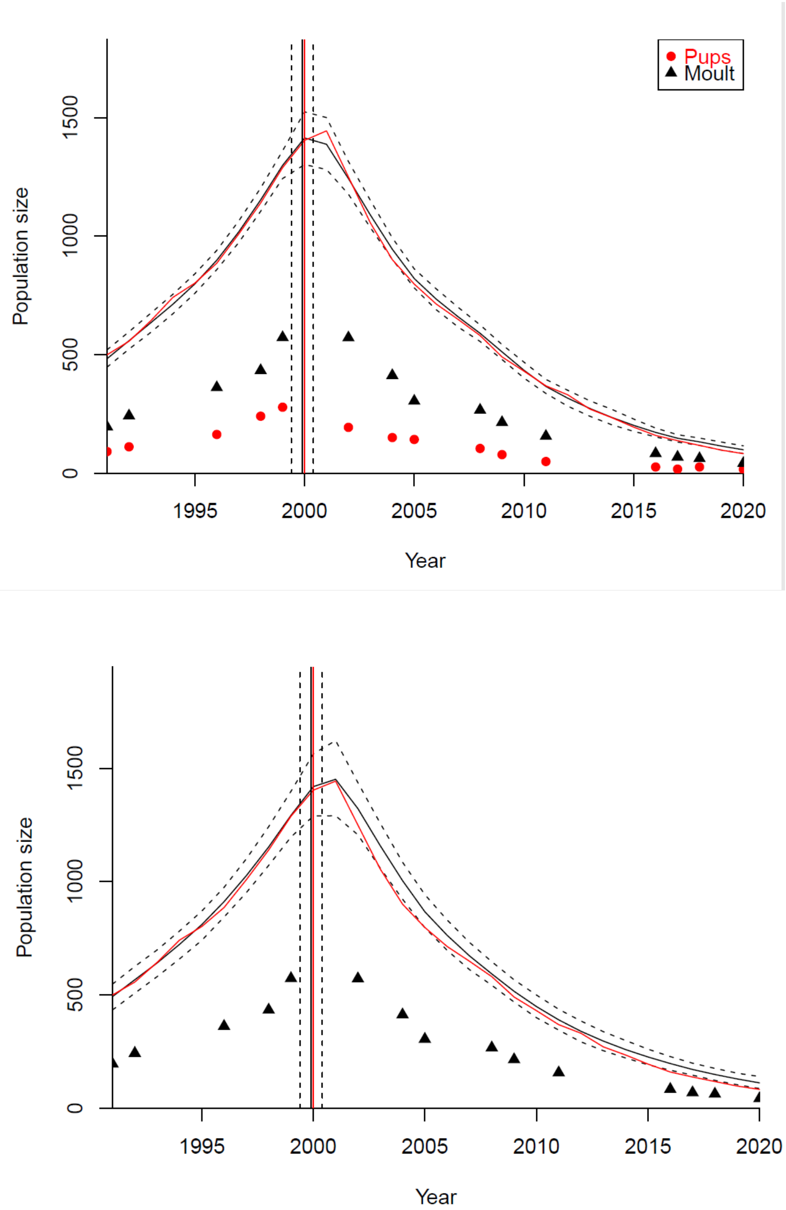


Figure 1. Population model showing estimated abundance and population trajectory (black lines) based on simulated (top) pup and moult counts and (bottom) moult counts only. Vertical black line = estimated change-point year when the population peaked in abundance, smoothed black line = estimated population trajectory, black dotted lines = uncertainty. The red smoothed line and the red vertical line are the true simulated population trajectory.

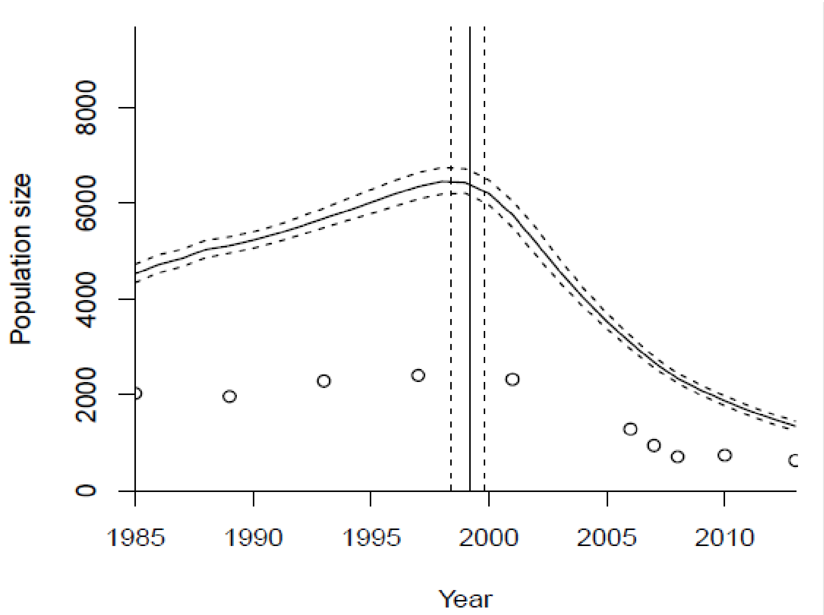
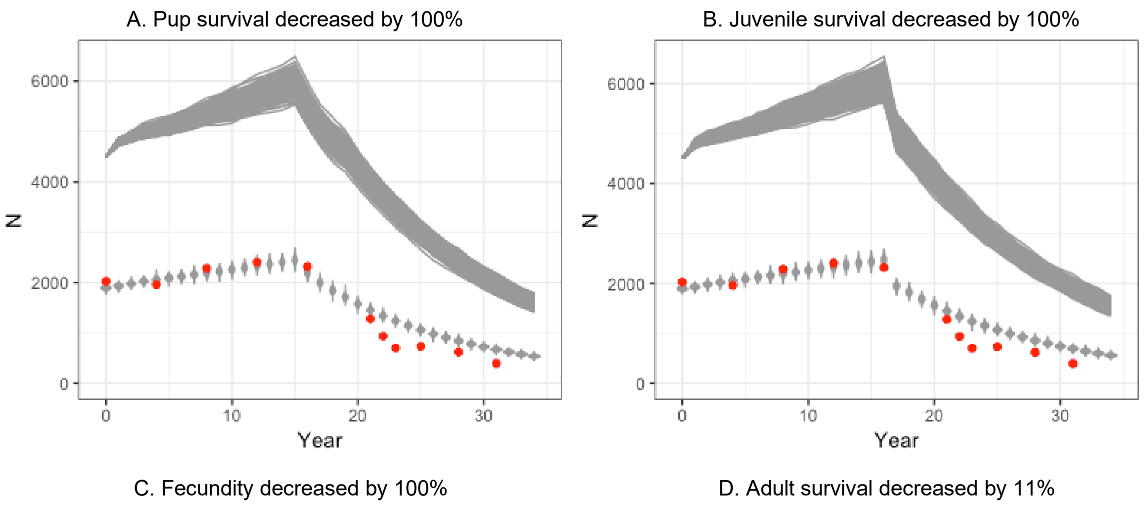


Figure 2. Time series of Scapa Flow surveys, estimated population size, and estimated ‘Change year’ in which mortality rate was estimated to have been changing most rapidly. The estimation was based on an age-structured population model fitted to the survey data, with changing mortality modelled as a scaled logistic function. Mortality was assumed to change across the full age range here, and the magnitude of this change was estimated at 0.15. Vertical line = change-point year when the population peaked in abundance, smoothed line = population trajectory, dotted lines = uncertainty.



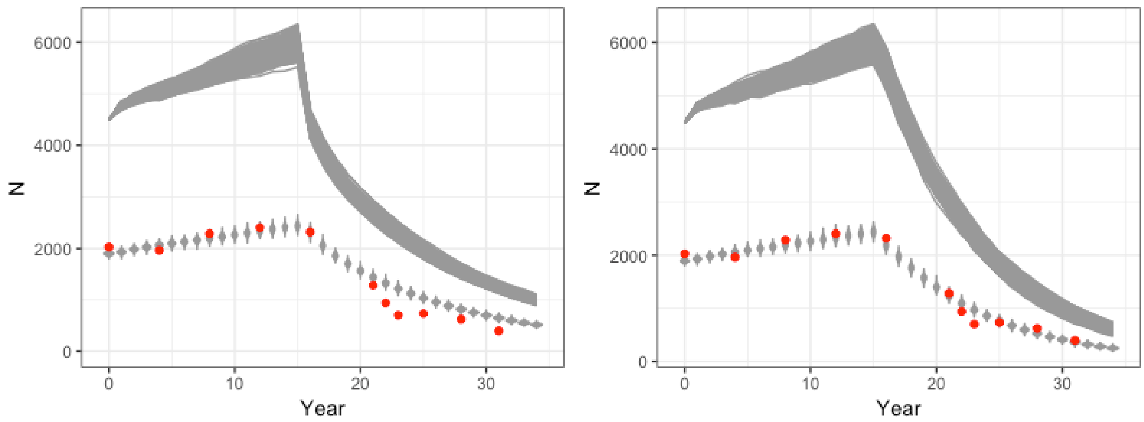


Figure 3. Results of simulated population trajectories with changes to vital rates. In each subplot, the grey lines indicate the simulated population size. The grey violin plots show the expected number of hauled out individuals in the population and the red dots show the observed number of hauled out individuals during the aerial survey count.

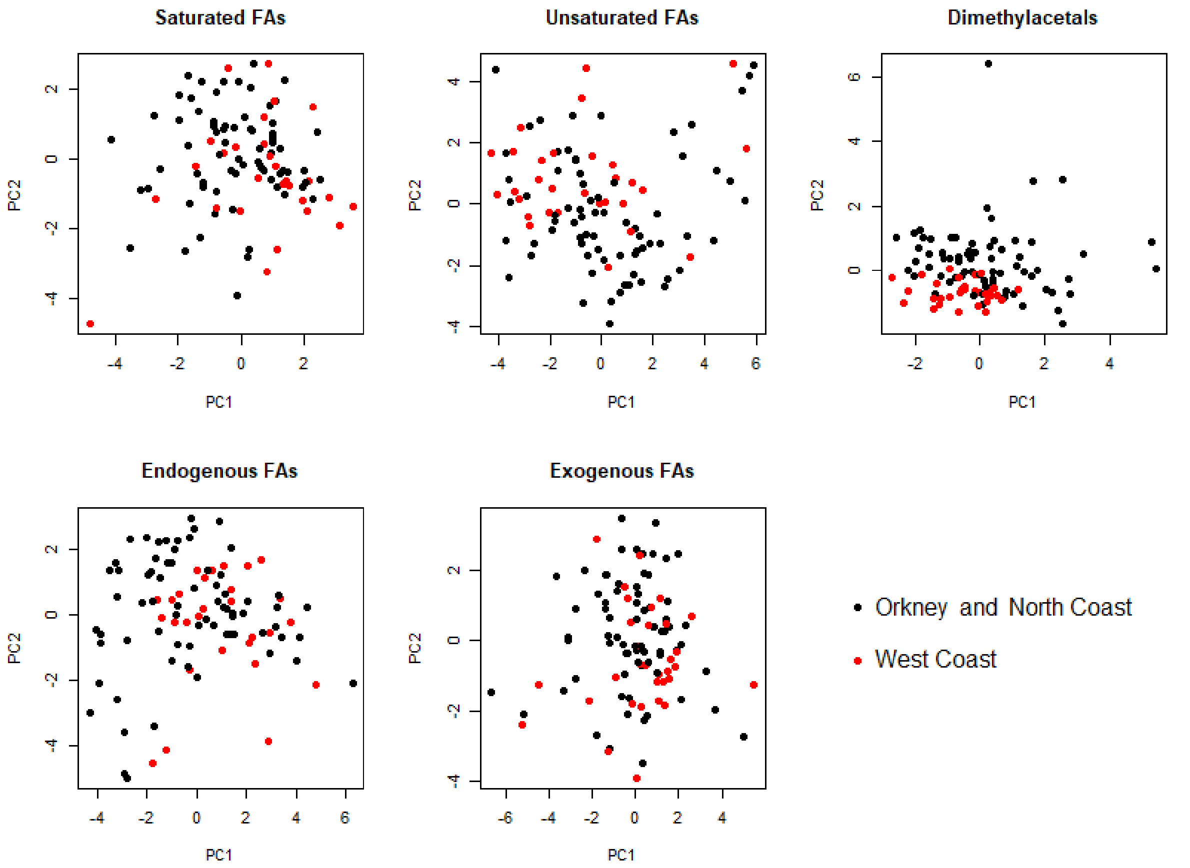


Figure 4. Plots of the PCA of the FA data classified into different functional groups. There was no clear clustering in any of the data by region with the exception of the dimethyl acetals.

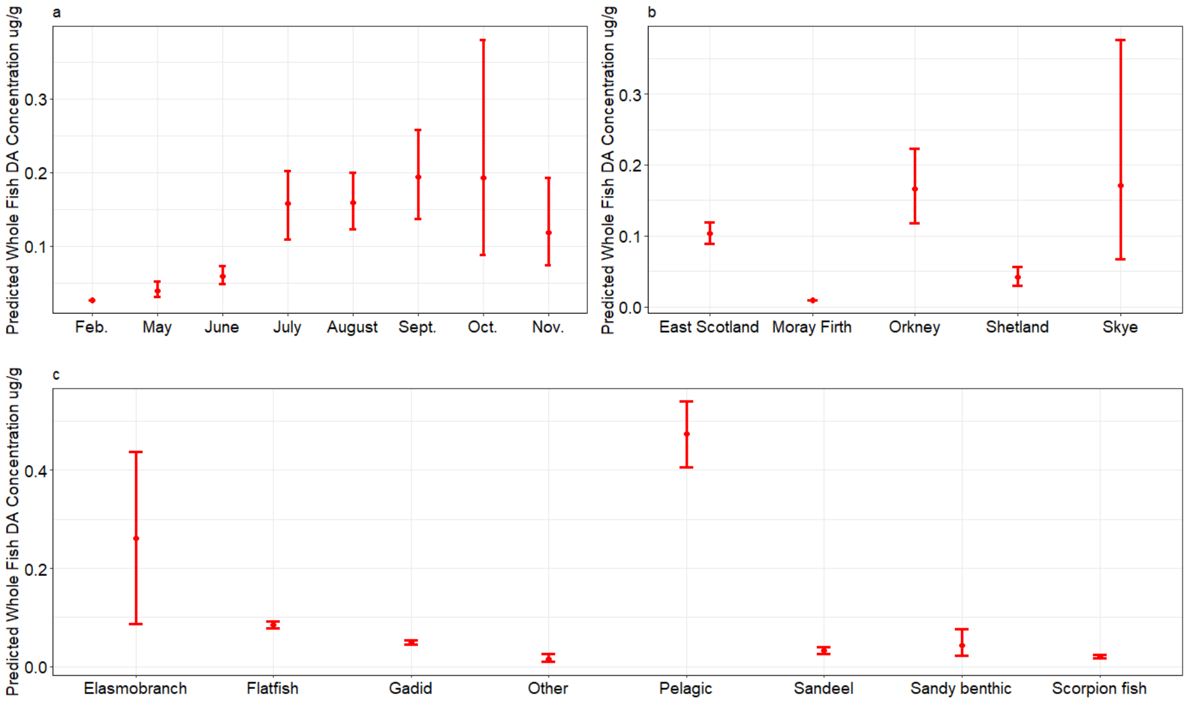


Figure 5. **Predicted whole fish DA concentrations for the best-fitting, *cosinor* GLM. a)** Predicted mean DA concentrations in fish increased over the year between February and November, ± 95% CIs. **b)** Predicted mean DA concentrations in fish varied across the 5 sampling regions of Scotland, ± 95% CIs. **c)** Predicted mean DA concentrations in fish varied between prey species groups, ± 95% CIs.

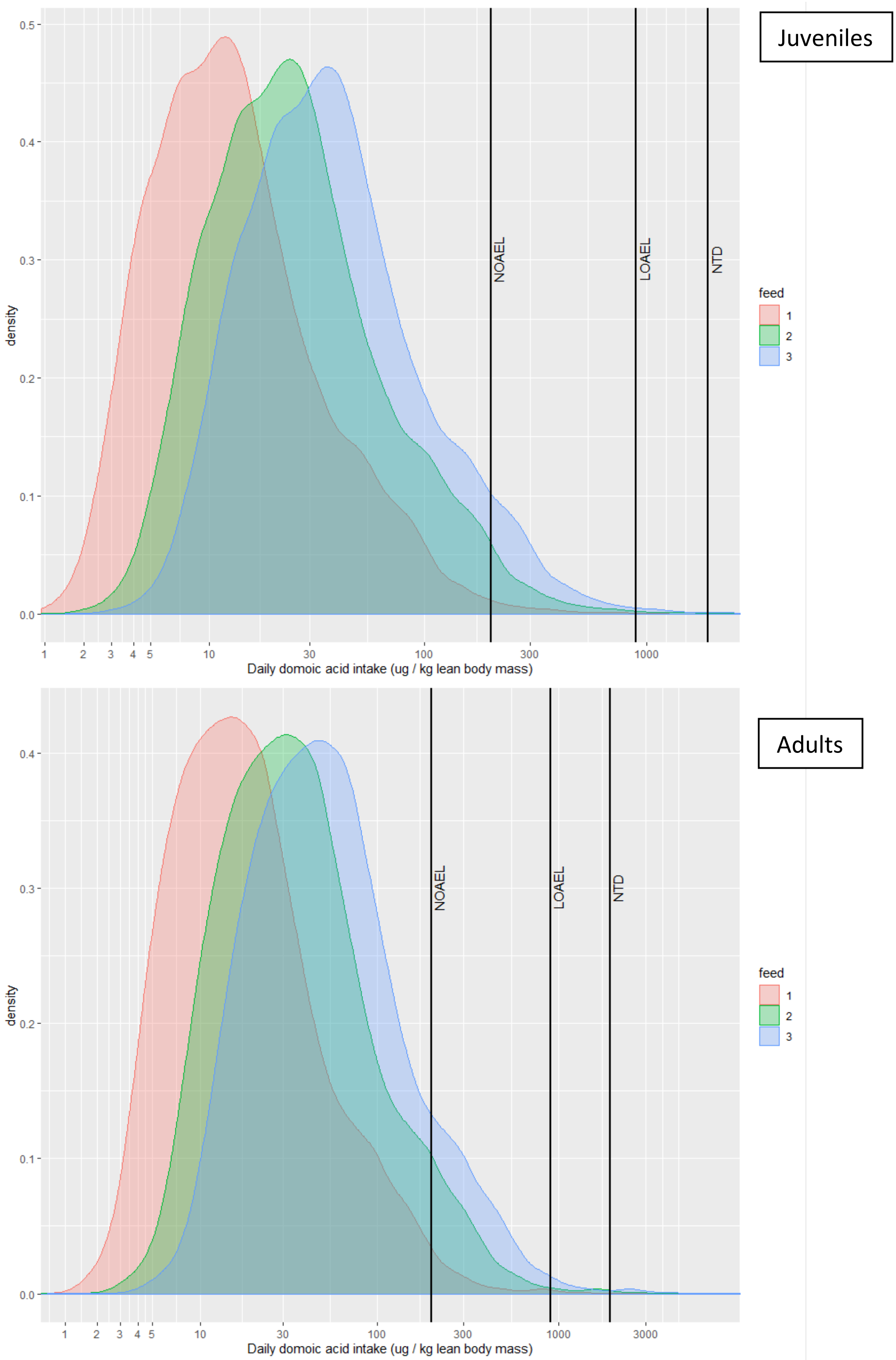


Figure 6. Daily domoic acid intake density plots from simulated seal feeding-days for adults (top) and juveniles (bottom) where the number of months of the year when HAB toxins persist is set to four. Each graph is grouped by feeding frequency: every day = 1 (red), every second day = 2 (green), every third day = 3 (blue). The vertical lines indicate three toxicity thresholds: NOAEL = no observable adverse effects level; LOAEL = lowest-observed-adverse-effect level; NTD = neurotoxic dose.

Table 1. Description of composite distributions resulting from the expert elicitation process. Quantities of interest (LL: lower limit, Q25: 25th quantile, Q50: median, Q75: 75th quantile, UL: upper limit) and shape parameters for beta distributions scaled within lower and upper limits to be used as informative priors for pup survival, juvenile survival, adult male survival, adult female survival, and fecundity.

	Quantities of Interest					Beta Parameters	
	LL	Q25	Q50	Q75	UL	Shape 1	Shape 2
Pup Survival	0.08	0.25	0.35	0.5	0.75	1.47	1.91
Juvenile Survival	0.65	0.75	0.8	0.85	0.95	2.16	2.16
Adult Male Survival	0.75	0.85	0.89	0.92	0.98	2.91	2.04
Adult Female Survival	0.85	0.92	0.94	0.96	1	3.76	2.58
Fecundity	0.5	0.84	0.88	0.92	0.98	7.13	2.05

Provisional Regional PBR values for Scottish seals in 2021

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Abstract

This document estimates PBR values for the grey and harbour seal "populations" that haul out in each of the seven Seal Management Areas in Scotland. Sets of possible values are tabulated for each area using the equation in Wade (1998) with different values of that equation's recovery factor. A value is suggested for this parameter in each population, the resulting PBR is highlighted, and a rationale is provided for each suggestion. The PBR values are calculated using the latest confirmed counts in each management area.

Changes since last year:
- Recovery factors have been held constant for both species in all management regions.
- The latest harbour seal survey counts for the North coast and Orkney and for the Moray Firth management regions were similar to previous counts and there has been no change in the PBR estimates for those management units.
- The grey seal counts for the North coast and Orkney and the Shetland management regions were approximately 12% and 35% respectively lower than previous estimates. The Moray Firth count was 115% higher than the previous count. These changes result in pro-rata changes in PBRs for grey seals in those management regions.

Introduction

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

Materials and Methods

The PBR calculation:

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

where:

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

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

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

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

The approach and calculation is discussed in detail in Wade (1998).

Data used in these calculations:

N_{min} values used in these calculations are from the most recent summer surveys of each area, for both species:

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

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

R_{max} is set at 0.12, the default value for pinnipeds, since very little information relevant to this parameter is available for Scottish seals. A lower value could be argued for, on the basis that the fastest recorded growth rate for the East Anglian harbour seal population has been below 10% (Lonergan et al. 2007), though that in the Wadden Sea has been consistently growing at slightly over 12% p.a. (Reijnders et al. 2010).

Regional pup production estimates for the UK grey seal population have also had maximum growth rates in the range 5-10% p.a. (Lonergan et al. 2011b). However, the large grey seal population at Sable Island in Canada has grown at nearly 13% p.a. for long periods(Bowen et al. 2003).

F_R needs to be chosen from the range [0.1, 1]. Estimated PBR values for the entire range of F_R values are presented. A recommended F_R value is indicated for each species in each region, together with a justification for the recommended value.

Areas used in the calculations:

Figure 1 and Table 1 shows the boundaries of the Seal Management Areas.
Particularly for grey seals, there will probably be substantial movement of animals between these areas. The division is a pragmatic compromise that attempts to balance current biological knowledge,

distances between major haul-outs, environmental conditions, the spatial structure of existing data, practical constraints on future data collection and management requirements

Rationale for the suggested recovery factors

The original PBR methodology leaves the setting of the recovery factor as a subjective choice for managers. Factors such as the amount of information available about the population (and in particular its maximum annual growth rate), recent trends in local abundance, and the connections to neighbouring populations are relevant to setting this. The main factors affecting the value suggested for each species in each area are given below:

Harbour seals

1) Shetland, Orkney + North Coast, and Eastern Scotland (F_R= 0.1)

F_R set to minimum because populations are experiencing prolonged declines and have not shown any signs of recovery.

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

3) West Scotland (F_R = 1.0)
The population is largely closed, likely to have limited interchange with much smaller adjacent populations. The most recent count was the highest ever recorded and the population is apparently stable or increasing.

4) South West Scotland (F_R = 0.7)
The population is apparently stable, is closed to the south and the adjacent population to the north is apparently stable or increasing. The intrinsic population growth rate is taken from other similar populations.

5) Moray Firth (F_R= 0.1)
Counts for 2019 in the Moray Firth were similar to the previous 5 years, confirming the absence of any overall trend over the past 15 years. The neighbouring Orkney and Tay populations are continuing to undergo unexplained, rapid and catastrophic declines in abundance. Data available from tracking studies suggest there is movement between these three areas. In the absence of a sustained increase in the Moray Firth counts it is recommended that the F_R should be left at its previously recommended value of 0.1.

Grey seals

All regions (F_R = 1.0)
There has been sustained growth in the numbers of pups born in all areas over the last 30 years. All UK populations are either increasing or apparently stable at the maximum levels ever recorded and therefore assumed to be at or close to their carrying capacities (Lonergan et al., 2011b; Thomas et

al., 2019; Russell et al., 2019). Available telemetry data and the differences in the regional patterns of pup production and summer haul-out counts (Lonergan et al. 2011a) also suggest substantial long-distance movements of individuals.

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

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

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Results

PBR values for grey and harbour seals for each Seal Management Area for with the full range of F_R values from 0.1 to 1.0 are given in table 1 for harbour seals and table 2 for grey seals. In each table the value corresponding to the recommended F_R is highlighted

Table 1. Potential Biological Removal (PBR) values for harbour seals in Scotland by Seal Management Unit for the year 2021. Recommended F_R values are highlighted in grey cells.

	2016-2019		PBRs based on recovery factors F_R ranging from 0.1 to 1.0										selected	
Seal Management Area	**count**	**N_{min}**	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**	**0.6**	**0.7**	**0.8**	**0.9**	**1.0**	**FR**	**PBR**
1 Southwest Scotland	1709	1709	10	20	30	41	51	61	**71**	82	92	102	0.7	**71**
2 West Scotland	15600	15600	93	187	280	374	468	561	655	748	842	**936**	1.0	**936**
3 Western Isles	3532	3532	21	42	63	84	**105**	127	148	169	190	211	0.5	**105**
4 North Coast & Orkney	1405	1405	**8**	16	25	33	42	50	59	67	75	84	0.1	**8**
5 Shetland	3180	3180	**19**	38	57	76	95	114	133	152	171	190	0.1	**19**
6 Moray Firth	1077	1077	**6**	12	19	25	32	38	45	51	58	64	0.1	**6**
7 East Scotland	343	343	**2**	4	6	8	10	12	14	16	18	20	0.1	**2**
SCOTLAND TOTAL	26846	26846	159	319	480	641	803	963	1125	1285	1446	1607		**1147**

Table 2. Potential Biological Removal (PBR) values for grey seals in Scotland by Seal Management Unit for the year 2021. Recommended F_R values are highlighted in grey cells.

	2016-2019		PBRs based on recovery factors F_R ranging from 0.1 to 1.0										selected	
Seal Management Area	**count**	**Nmin**	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**	**0.6**	**0.7**	**0.8**	**0.9**	**1.0**	**FR**	**PBR**
1 Southwest Scotland	517	1995	11	23	35	47	59	71	83	95	107	**119**	1.0	**119**
2 West Scotland	4174	16111	96	193	289	386	483	579	676	773	869	**966**	1.0	**966**
3 Western Isles	5773	22283	133	267	401	534	668	802	935	1069	1203	**1336**	1.0	**1336**
4 North Coast & Orkney	8599	33192	199	398	597	796	995	1194	1394	1593	1792	**1991**	1.0	**1991**
5 Shetland	1009	3894	23	46	70	93	116	140	163	186	210	**233**	1.0	**233**
6 Moray Firth	1657	6396	38	76	115	153	191	230	268	307	345	**383**	1.0	**383**
7 East Scotland	3683	14216	85	170	255	341	426	511	597	682	767	**852**	1.0	**852**
SCOTLAND TOTAL	**25412**	**98087**	**585**	**1173**	**1762**	**2350**	**2938**	**3527**	**4116**	**4705**	**5293**	**5880**		**5880**

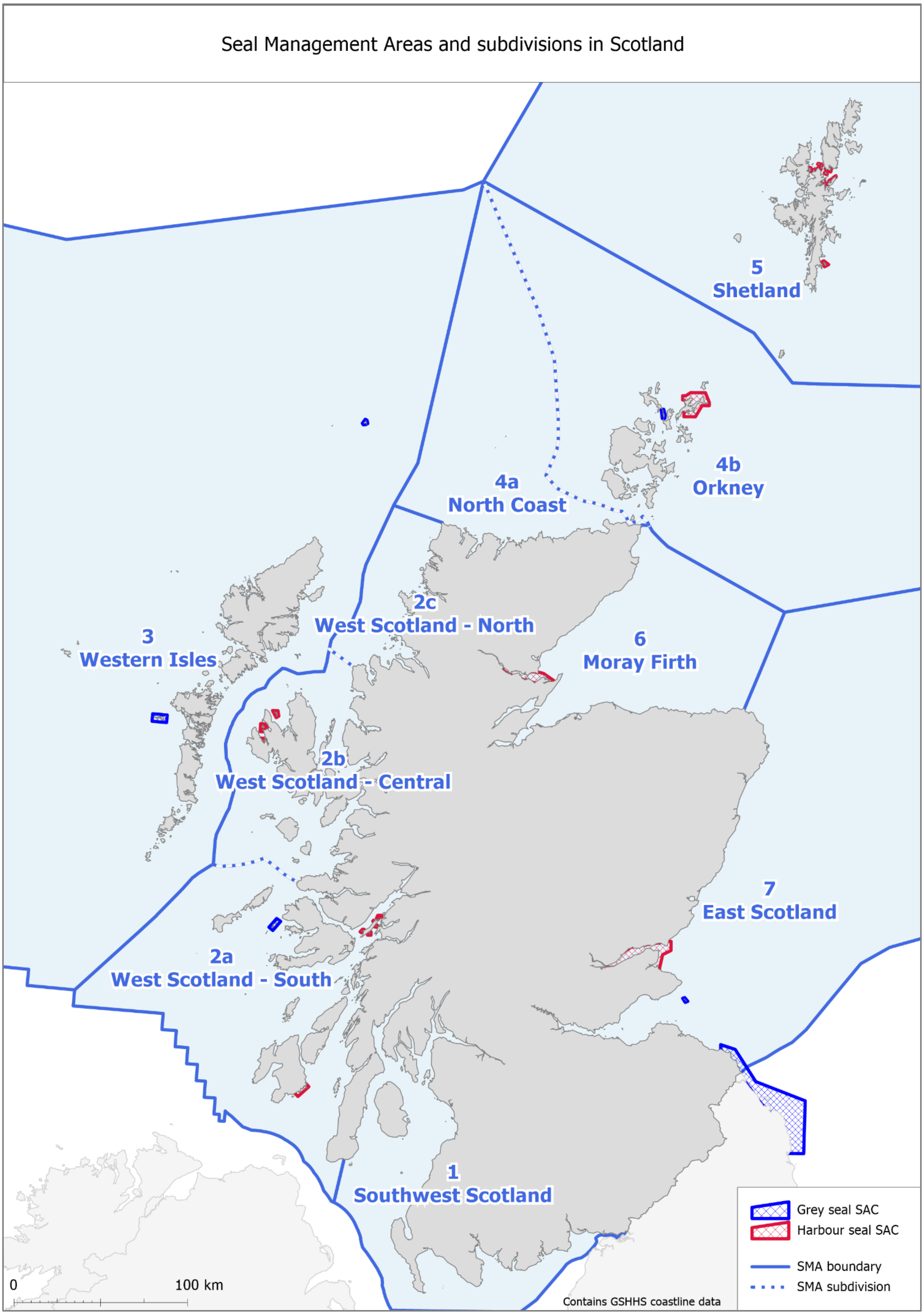

Figure 1. .Seal management areas in Scotland. For purposes of PBR calculations West Scotland is

Options for lethal removal of seals in Scotland

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Abstract

Where lethal removal is required as part of a seal management strategy there are currently only three options:

- shooting of free-ranging seals,
- seal capture followed by lethal injection,
- seal capture followed by shooting.

There is limited and potentially biased information on the welfare implications of shooting, but from limited data available it is clear that a proportion of shot seals were not killed instantaneously. Ballistics studies suggest that .308 rifles should be the minimum calibre weapons for shooting seals to ensure the animal is immediately rendered unconscious. It is imperative that seals are killed as painlessly as possible and some mechanism is required to ensure a seal isn't left alive after being shot. Any seal that shows signs of consciousness should be dispatched as soon as it is safe to do so.

If the seal sinks immediately after being shot an effective watch should be maintained in case the animal was only wounded and re-surfaces. Every effort should be made to retrieve the shot seal as soon as possible to confirm that it is dead. The ability to recover the seal/carcass should be a consideration in decisions on whether to shoot a seal and on where and when to shoot.

The lack of effective seal catching methods both in rivers and at sea limits the application of other methods. Both lethal injection and shooting of restrained animals are potentially effective methods, but to do so would require the involvement of specialist veterinary expertise to protect human safety and animal welfare. Catching, handling and transporting of seals does induce fear and distress, and is therefore a welfare consideration.

It is difficult to directly compare the welfare aspects of shooting free ranging seals with the welfare aspects of capturing seals before lethal injection or shooting. In one case an unknown proportion of seals may suffer severe pain and drowning in the other case all seals will be subjected to the stress effects of capture and handling.

Introduction

Several reviews of seal killing methods have been published, notably EFSA (2007), NAMMCO (2009), Morner *et al*. (2013) and Nunny *et al*. (2018). However, the majority of these have been concerned with seal hunting and primarily with welfare aspects of the hunting of seal pups. Nunny et al. (2016) reviewed the seal licensing system in Scotland and the effect of shooting on the welfare of seals. None of these studies, however, have addressed the issue of seal capture and lethal injection and none compare and rank the available methods in terms of animal welfare.

If lethal removal is required as part of a seal management strategy, there are currently only three options.

- shooting of free-ranging seals,
- seal capture followed by lethal injection,

- seal capture followed by shooting.

A fourth option that has been employed as a hunting method is to set submerged tangle nets that drown the seal. For a diving mammal, adapted to extended breath-hold dives, any killing method that involves holding the individual under water would be extremely distressing and impose unnecessary suffering. NAMMCO (2009) reviewed seal hunting methods and concluded that the limited data available on entanglement of seals do not allow assessment of the extent of suffering experienced by the seals, but EFSA (2007) simply state that some methods of killing seals are inhumane e.g. trapping seals underwater until they die, and should not be used. Setting nets to catch and drown seals in the UK would be unacceptable and, in any case, drowning seals is illegal in the UK under the Wild Mammal Protection Act 1996.

Shooting seals in the water

Seals in Scotland can currently only be shot under licence and with “a rifle using ammunition with a muzzle energy not less than 600-foot pounds and a bullet weighing not less than 45 grains” (Marine (Scotland) Act 2010). The Scottish Seal Management Code of Practice recommends a shot to the head and centre fire rifles with expanding bullets should be used for public safety and animal welfare reasons (Marine (Scotland) Act 2010).

In practice, only head shots are feasible for seals in the water as that is usually the only part of the animal that is visible above the surface.

Effectiveness/welfare aspects of shooting

Licences to shoot seals state that if a seal is not killed immediately, the marksman should 'take all reasonable steps to take away suffering of injured seals, by locating and humanely killing such animals as soon as possible, and without delay, following their being injured'. It is a condition of the seal licence that, where possible, reasonable steps should be taken to recover carcasses. One reason for requiring carcass recovery is to allow an assessment of whether seals are being killed humanely.

The Scottish Marine Animal Stranding Scheme (SMASS) based at Scotland’s Rural College (SRUC) Wildlife Unit have conducted a total of 47 post-mortems on seals between 2012 and 2019 and a further five were examined by SMRU, that were either reported as having been shot under the licence scheme or were assessed to have been shot on the basis of post mortem results (Brownlow and Davison, 2012,2013,2014,2015; SRUC Wildlife Unit unpublished data). Injuries recorded during post-mortems were used to assess whether the seals were likely to have been killed or rendered unconscious instantaneously.

The majority (48 out of 52 cases) of shot seals necropsied at SRUC and SMRU were found to have been shot effectively with a single shot destroying the cranial vault. However, in 2012 two seals showed signs of multiple gunshot wounds and blood aspiration (Brownlow & Davison, 2012); in 2013, one seal had been shot in the neck and, in 2014, one had been shot through the mandible (Brownlow and Davison, 2013, 2014). While it is not known if the wounded seals were shot under licence, it is clear that 4 out of the 52 seals examined were not killed instantly, although it is not clear how many of those would have been instantaneously rendered unconscious.

Only a small percentage of the seals reported as shot to the Scottish Government, were available to SMASS, as a result only 3.6% of the reported shot seals were necropsied. Even where carcasses of shot seals are recovered, some are found at later dates and distant from the reported shooting location, so it is often difficult or impossible to confirm that they are the same seals that were reported shot under licence. The sample is also likely to be biased, although we have no empirical evidence to inform the nature and direction of any biases. For example, it is possible that wounded but conscious seals will move away from the shooting location and be less likely to be subsequently recovered. Conversely it is also possible that wounded seals that have to be shot more than once, may be more accessible and their carcasses could be more likely to be retrieved. There is also a possibility that carcasses of 'clean kills' may be more likely to be recovered. Therefore, due to the low recovery rate and uncertainties around the probability of recovery under different circumstances, the seals recovered by SMASS cannot be regarded as a representative sample of those shot.

The number of carcasses recovered remains low, with between one and three carcasses (3-4% of killed seals) recovered annually between 2015 and 2018. A total of 11 carcasses (11% of killed seals) were recovered in 2019, suggesting that the situation may be improving. As part of continuing efforts to improve recovery rates, Marine Scotland issued a further reminder letter alongside the licences issued in February 2020. This letter reminded licensees of their duty to recover carcasses and details of how to do so, in addition to reminding them to report recovered carcass to SMASS.

In conclusion, using the available necropsy data could produce widely inaccurate estimates of the proportion of seals shot but not immediately rendered unconscious and in the absence of a lot more data we cannot confidently assess the likelihood of instant kill versus wounding. However, despite these limitations, the current necropsy results clearly indicate that a proportion of the seals shot in Scotland were not killed instantly by the first shot. Given the potential biases and the small sample size, the necropsy results should not be used as a realistic estimate of the proportion and from a precautionary perspective should be seen as a minimum.

Ensuring rapid death/minimising suffering

Regulations applied to the commercial hunt of harp and hooded seals in Canada require that hunters immediately ascertain that the skull of a shot or clubbed seal has been shattered and that the seal has been rendered unconscious or killed outright. If the skull appears to be intact, the seal must be either shot or clubbed again. Once the seal is confirmed to be unconscious it must then be exsanguinated. This is designed as a fail-safe to ensure that seals are dead and not simply unconscious before they are skinned, to avoid the possibility of any seal regaining consciousness during the skinning process. This measure would not be necessary in the seal management scenarios in Scottish rivers as seals will not be skinned.

However, it is imperative that seals are killed as painlessly as possible and some mechanism is required to ensure a seal isn't left alive after being shot. Therefore, any seal that floats after being shot should be assessed. If it shows any signs of consciousness, e.g. movement, or if it is apparently still breathing, it should again be shot in the head as soon as it is safe to do so.

If the seal sinks immediately after being shot it is likely to be either dead or unconscious and will almost certainly drown before regaining consciousness. However, in such circumstances the shooter must maintain an effective watch for a suitable period in case the animal was only wounded and re-surfaces. It must then be shot and killed as soon as it is safe to do so. The duration of the watch period should be based on the observed dive behaviour of seals. For grey seals >95% of dives are less than 11 minutes long and 99.9% of dives are less than 30 minutes long (Thompson *et al*., 1991; Thompson & Fedak, 1993; Goulet, Hammill and Barrette, 2001), and harbour seal dives are generally shorter, >95% of dives are less than 7 minutes long (Bjorge *et al*. 1995).

Every effort should be made to retrieve the shot seal as soon as possible. It is already a condition of seal licences in Scotland that carcasses should be retrieved where possible, but the recovery rate is inadequate, and this requirement has not hitherto been enforced. The licensing authority should continue efforts to enforce the requirement. The ability to recover the seal/carcass should be a consideration in decisions on whether to shoot a seal and on where and when to shoot. E.g. in Canada seal hunting regulations state that anyone hunting seals must have "on hand the equipment that is necessary to retrieve it".

Suitability of firearms

A study was carried out in 2011 (SRUC, 2016) to investigate the effects of different ammunition on the heads of seal cadavers in order to assess the minimum ballistic specification required for the humane killing of seals by rifle shooting.

Seal heads were placed in a realistic pose representing the head of a seal at the water surface and trained marksmen fired at the heads from a range of 50m. The marksmen targeted the seal face-on, i.e. targeting the nose of each seal head, so the bullet entered the frontal region on a sagittal trajectory. This was chosen to represent the worst-case scenario, with the largest amount of tissue between the entry point of the bullet and the brain. One seal head was shot from the side with a small calibre .223 Remington jacketed hollow point, 45 grain.

The small number of available seal cadaver heads prevented replication, so the sample size is limiting. However, based on CT scans and a standard trauma scoring system, the following ballistics produced profound skull trauma which would likely have caused immediate loss of consciousness and death:

22-250 Winchester 55 grain pointed soft point
.308 Remington 125 grain core-lokt psp
12 bore Shotgun (used for humane dispatch at 5 metres)

The following ballistics did not reliably produce catastrophic skull trauma likely to cause immediate loss of consciousness and death:

.223 Remington jacketed hollow point, 45 grain
.223 Federal hi-shock soft point 55 grain
243 Remington 100 grain core lokt
12 bore Shotgun (used for humane dispatch at 15 metres)

The pathologists involved considered that the injuries resulting from a frontal shot on a sagittal plane would probably have caused a seal to lose consciousness, but this cannot be confirmed. The seal head that was shot laterally, with a .223 Remington jacketed 45 grain hollow point, displayed severe skull trauma that would have been instantaneously fatal.

The study concluded that to reliably cause instantaneous death a .308 calibre rifle firing 125 grain bullets should be used for shooting free swimming seals. They suggest that since .308 rifles are widely used in deer culling, they are likely available to most marksmen.

Mörner et al. (2013) examined 29 carcasses of grey seals shot in modified salmon trap nets and tested a similar range of firearms and ammunition to those in the SRUC trials. However, in all cases the seals were shot from the side and at closer range than in the SRUC trials. Based on observations of animals after shooting and necropsies, they concluded that all seals were rendered immediately unconscious or instantly killed. However, four of the seals were shot twice, suggesting that at least that number were not killed outright by the first shot.

Training

In Scotland all marksmen must possess an appropriate firearms certificate and are required to complete a Professional Development Award (PDA) in seal management which assesses their skills and experience for operating as marksmen under the seal licensing system.

Seal capture

The possibility of wounding a seal would be removed if the animals were first caught or restrained before killing. However, there are both practical and animal welfare considerations associated with seal capture and unlike effective head shots, seal capture will involve a protracted period of fear and stress for the animal.

While successful techniques have been developed for catching seals on land and in the water at coastal haulout locations, methods for catching free swimming seals in open water and in swift flowing river environments are less well developed.

In rivers

Capture techniques based on floating haulout traps that are used for routine capture and recapture of individual California sea lions in US rivers are not applicable to UK seals. Sea lions are gregarious and frequently haulout on platforms and floating structure even in close proximity to human activity. Harbour and grey seals in Scotland do not regularly use such structures, are much more wary of human activity and rarely haulout on land when in rivers.

In Scotland, methods have been developed 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 & Harris, 2010). However, success relied on first gathering considerable behavioural knowledge for specific individuals. That study highlighted the difficulty, and level of manpower resources required to catch a small number of seals, in the relatively benign conditions of small, slow flowing rivers. The exact time required for the development of sufficient knowledge to successfully catch seals is hard to predict but is likely to be in the region of weeks, at least initially.

Catching free swimming seals in larger, faster flowing rivers will be considerably more challenging. Harris & Northridge (2018a) explored new approaches for capturing seals in larger rivers including capture at one of the few in-river haulout sites, developing a floating baited cage trap and testing various sweep netting and tangle netting options. The initial work showed that the methods have potential but have not been tested sufficiently to assess their effectiveness.

At present therefore, the utility of lethal removal following capture is constrained by the lack of efficient methods for catching seals in rivers. Further development and practice would be required to prove and optimise catching methods in rivers.

At finfish farm sites

Catching seals in the open sea or in deep water around finfish farm sites is problematic. Simple floating tangle nets, with the float line anchored to the seabed and with a light lead line so that seals can easily access the surface, have been used safely and successfully to catch both grey and harbour seals (SMRU unpublished). However, the method is often unsuccessful and requires a large investment of time by a highly trained/experienced team of seal catchers.

Pontoon traps designed for catching salmon have been modified in Sweden to produce effective seal traps (Lehtonen & Suuronen, 2010). Seals enter the multi chamber net through an entrance fitted with a sprung trapdoor. Seals attempting to enter an inner chamber trigger the trapdoor and trap the seal in the outer chamber where they can access the surface to breathe. The pontoon traps are similar in structure and operation to Scottish salmon bag nets. Swedish national regulations require that all new models of traps for catching and holding and/or euthanizing animals must be acceptable in terms of animal welfare. The modified pontoon traps received official approval after post-mortem examination for signs of stress and physical trauma in 20 individual grey seals that were euthanized after capture in such traps (Königson et al. 2013). The seals caught in the traps were apparently specialist pontoon trap raiders (Königson et al. 2013) and it is not clear how effective such traps would be in catching naïve seals in the open sea.

Capture stress

If successful capture methods are developed, they will likely involve some combination of active seine netting, use of floating tangle nets, or semi-submerged baited traps. All such methods will be stressful for any seals caught. The duration and magnitude of that elevated stress will depend on the method employed, the location and local conditions at time of capture and the speed of response by the catching teams.

Acute and chronic changes in cortisol in response to either capture or handling stress have been examined in northern elephant seals (*Mirounga angustirostris*) (Champagne et al. 2012), southern elephant seals (*M. leonina*) (Engelhard et al. 2002), adult male grey seals (Lidgard et al. 2008), Weddell seals (*Leptonychotes weddelli*; Harcourt et al., 2010), rehabilitated Pacific harbour seals (Gulland et al. 1999), and wild California sea lion pups (Padernera-Romano et al. 2010). However, these studies all assessed acute and chronic responses in terms of their potential longer-term impacts on growth, survival and reproductive performance. None addressed the immediate welfare aspects of elevated stress.

One study (Bennett et al. 2011) suggested that routine handling of grey seal pups had no additional impact over and above that of general disturbance caused by researchers moving around the breeding colony. But, conversely, both adult harbour seals (Wilson, 1972) and fur seal pups (Seguel et al. 2014) have been reported to demonstrate capture myopathy, which suggests that handling stress may be severe in some circumstances.

Any method involving active netting or passive tangle netting will entail some risk of drowning. The animal welfare aspects of drowning an animal adapted for long duration breath-hold dives are obvious and have led to the banning of netting for hunting seals in most countries. Highly skilled, well trained personnel in dedicated catching teams will be needed to minimise these risks and rigorous protocols will need to be developed to minimise such risks.

Irrespective of the killing method, every effort should be made to minimise the duration of the capture time in order to minimise distress to the seal. In terms of ranking capture methods, it is likely that baited traps, if they were trialled and found to be effective, would be less stressful than other netting methods which would involve physical restraint of the seal.

Training

Handling nets in fast flowing rivers is difficult and potentially dangerous. Removing seals from traps and or nets in the water is an extremely difficult and potentially hazardous task and can only be attempted by highly trained and experienced staff. In the longer term, if seal catching is to be required for seal management, there will be a requirement for a highly skilled/well trained team of seal catchers. The opportunities for training staff in such techniques are limited.

Methods for killing captured seals

Two alternative methods are available.

Gun shot.

SRUC's ballistics study suggested that a 12-bore shot gun would reliably kill a seal at ranges of less than 5m. However, restraining a seal in such a way as to guarantee an accurate shot will be difficult. Seals in nets can be dragged ashore. Experience of seal catching in coastal waters suggests that when held in a hoop net, seals usually became stationary for periods of time. A trained marksman should be able to use such stationary periods to dispatch a seal. If a first shot is not lethal, the shooter should be ready to fire a second shot within seconds that would end the seal's suffering.

Morner et al. (2013) investigated the effect of different firearm calibres on the likelihood of killing grey seals caught in traps in the Baltic Sea. This study found that rifles with a 5.6 mm bullet or larger, and a .12 bore shotgun loaded with a slug fired at close range to the head and neck of grey seals all caused instant death.

The use of a firearm on a trapped/entangled seal at ranges of less than 5m poses clear risks to the shooter from ricochets. However, protocols and good firearm practices should minimise or remove those risks and ensure instant death for the seal.

Lethal injection.

Only one method of drug induced euthanasia is currently available for seals in the UK, intravenous injection of Pentobarbitone. The only relatively easily accessible injection route will be through the extradural vein. This will require that the seal is first sedated, using one of the regularly administered anaesthetics such as zoletil or ketamine. Again, these anaesthetics are usually administered via the extradural vein, but in the case of a seal to be euthanised, a simpler intramuscular injection of anaesthetic may be sufficient to immobilise and would be less stressful for the seal.

Pentobarbitone is extremely dangerous and a lethal dose injection means that the carcass poses a serious risk of poisoning to other wildlife and domestic animals. It is therefore absolutely essential that the carcasses of any seals killed with Pentobarbitone are kept secure and transported to SMASS for post-mortem and eventual controlled disposal. Post-mortem analysis will allow an assessment of the state of the seal prior to death and allow an appraisal of the welfare issues involved in the animal's response to capture and handling.

Training

Administering both anaesthetics and Pentobarbitone will require a qualified and specifically trained veterinarian, experienced in injection into the extradural veins of seals. Anyone performing euthanasia should be able to identify when death has occurred. Standard methods for ascertaining death in euthanasia of cats and dogs such as absence of chest movement / signs of respiration and undetectable pulse may be less obvious in seals which regularly perform extended breath-holds and can reduce heart rates to only a few beats per minute. Absence of corneal reflex (blink reflex), loss of colour from the mucous membranes in the animal's mouth and eventually rigor mortis are more reliable signs of death in a seal.

Additional welfare concerns

One additional welfare concern, expressed by Nunny et al. (2016), was the possibility of a shot female seal having dependent young. If this is a concern it will apply to all methods of lethal removal and therefore is not a useful consideration for ranking methods based on animal welfare perspective.

For grey seals in rivers this is not an issue as lactating females generally stay on or close to the pupping site. For harbour seals, although females forage during lactation, it is unlikely that they would be resident in rivers during that period. Even if they were, the problem would only relate to the period of June and July and could therefore be avoided by not shooting seals in these months.

The same arguments apply to seals at fish farms. But it is a potential problem for female harbour seals that make extensive foraging trips during lactation and may forage around fish farms.

Relevant regulation

In Scotland it is an offence to kill, injure or take a seal (recklessly or intentionally); the only exceptions being to alleviate suffering or under licence (Marine (Scotland) Act 2010).

The Marine (Scotland) Act 2010 specifies the minimum calibre and muzzle velocity of firearms that can be used if seals are to be killed by shooting, however, it does not specifically prohibit other methods of killing. The Marine (Scotland) Act 2010 states that the method of killing should be detailed in any licence.

Euthanasia usually defined as 'painless killing to relieve suffering' (RCVS, 2020), is not classed as an act of veterinary surgery, and in most circumstances may be carried out by anyone provided that it is carried out humanely. RCVS guidelines do acknowledge that in some circumstances healthy animals may need to be killed but also indicate that no veterinary surgeon is obliged to kill a healthy animal unless required to do so under statutory powers as part of their conditions of employment.

Generally, only veterinary surgeons and veterinary nurses acting under their direction and in accordance with Schedule 3 of the Veterinary Surgeons Act, have access to the controlled drugs often used to carry out the euthanasia of animals.

The Conservation (Natural Habitats, &c.) Regulations 1994 and the Conservation of Habitats and Species Regulations 2017 specifically prohibit the use of nets and traps which are non-selective according to their principle or their conditions of use. However, using nets and traps in active attempts to live-catch specific individual seals should not contravene the Conservation (Natural Habitats, &c.) Regulations 1994 and the Conservation of Habitats and Species Regulations 2017, but this may need to be discussed if such methods are to be used in seal management.

Conclusions

A framework for assessing the welfare implications of vertebrate pest control (Littin et al. 2014) considered that the following factors should be considered in any comparison:

- time of onset of the first signs that the animal is affected

- the time of onset and duration of each sign or effect, plus an indication of the degree of impact (e.g. mild, moderate or severe breathlessness or injury)
- the time to loss of consciousness using an agreed indicator
- other impacts of the technique that may influence (increase or decrease) the degree or duration of negative impacts experienced by the animal, for example, neurological impairment, sedation, analgesia or fear

The absence of data means that it is difficult to quantify the welfare implications for individuals and therefore it is not possible to objectively compare between the methods discussed here using such a framework. It is likely that under ideal conditions, where a clean shot can be achieved (within 5m for captured seal, within 150m and to the side of the head, or a general head shot with a .308 calibre rifle) that shooting free-ranging animals would rank as a better, more humane method taking these factors into account. However, the absence of knowledge on how often these circumstances are being met in practice, alongside uncertainties in relation to the ability to capture seals makes this difficult to conclude with any confidence. It is likely that the time between the start of any capture attempts and the onset of unconsciousness prior to death could be considerable for any method involving capture.

There are insufficient data to accurately or reliably assess the effectiveness of current seal shooting practices to deliver a clean painless kill. More carcass recovery is required to allow an assessment to be made. However, available information suggests that a proportion of shot seals were not killed instantaneously, so a problem of unknown magnitude exists. Use of .308 calibre rifles would significantly reduce the possibility of shot animals remaining conscious and potentially remove that problem.

Seal capture methods in rivers are challenging, time consuming and inefficient and in some situations seal capture will not be possible. This limits the possibilities for capture and dispatch by either gun shot or lethal injections.

Capture stress is a significant issue, but there are no reliable methods for comparing the welfare costs of short-term exposure of all animals to potentially severe capture stress against the potentially severe pain to a smaller number of seals that may not be killed outright.

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