Scientific Advice on Matters Related to the Management of Seal Populations: 2013

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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 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 2013, 44 questions were addressed by SCOS.

These included assessing the current population dynamics and trends for the two species of UK seal (harbour or common and grey seals); investigating the factors that are currently affecting those trends; assessing the interactions between seals and salmon; assessing the effects of marine renewable energy developments and the disturbance this may cause and the potential impacts of climate change.

Population trends

Grey seal population trends are assessed from the counts of pups born during the autumn breeding season. A change in the air survey methods in 2012 resulted in a greater number of photographs and a delay in providing the 2012 estimates. Therefore, the most recent complete UK grey seal pup production estimate remains the 2010 estimate which was 50,200 (95% CI 47,500-52,900). To then estimate the total grey seal population size in 2012, trajectories from a population dynamics model using the pup counts and population demographic parameters gave an estimate of 112,300 (95% CI 90,600-142,900) UK grey seals.

Harbour seals are counted while they are on land during their August moult, giving a <u>minimum</u> estimate of population size. Not all areas are counted every year but the aim is to cover the UK coast every 5 years.

Combining the most recent counts (2007-2012) gives a total of 26,836 counted in the UK. Scaling this by the estimated proportion hauled out produced an estimated total population for the UK in 2012 of 37,300 (approximate 95% CI 30,500 – 49,700).

Harbour seal counts were stable or increasing until around 2000 when declines were seen in Shetland (which has declined by 30% since 2000), Orkney (down 75% since 2000) and the Firth of Tay (down 85% since 2000). However, other regions are now stable following a period of decline (the Moray Firth) and some have been largely continually stable (west coast of Highland region and the Outer Hebrides). By contrast, counts along the English east coast were 18% higher than in 2011 and are now above the counts obtained before the 2002 phocine distemper virus (PDV) epidemic. 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 moulting surveys. Information on vital rates would improve our ability to provide advice on population status.

Research into the causes of the decline in harbour seals is continuing. This is currently focussed on the potential for competition with grey seals through investigations into dietary and foraging area overlap; investigations into the impact of disease, particularly the ingestion of toxins from harmful algae and physical trauma as a major cause of mortality in some regions.

In relation to deaths due to physical trauma, research into the causes of the recently identified unusual mortalities (“corkscrew” seal deaths) is continuing. The hypothetical link between these traumatic deaths and ducted propellers is being tested using scale models in industrial test facilities. The hypothesis that seals are acoustically attracted to certain propellers is also being tested in the SMRU captive seal facility and in the wild through behavioural sound playback studies.

Movements and foraging

The latest results from satellite tagging in respect of usage of specific coast and marine areas around the UK by grey and harbour seals and whether these suggest potential foraging sites are presented. Refined, population scale, at–sea usage maps for grey and harbour seals have been developed using the telemetry data obtained from both grey and harbour seals.

Seals and salmon

Studies suggest that specialist seals are responsible for the majority of seal activity and presumably predation events at netting stations. Acoustic deterrent devices (ADDs) are effective in reducing seal activity and predation. In a recent study during periods when an ADD was switched *on*, significantly fewer seals were observed and significantly more fish were landed per hour than when the ADD was switched *off*.

Current studies have found that there does not seem to be any relationship between damage levels at different salmon farm locations and the proximity or local density of seals. ADDs are also used to deter seals from these sites but there are concerns about their effect on cetaceans and the need to ensure they operate reliably. Increased or improved application of standard husbandry techniques, notably cage structure and net tensioning, can substantially reduce the incidence of seal damage to farmed salmon.

Seals and marine renewable energy

Research into the interactions between seals and marine renewable devices is continuing. The only direct information on interactions between seals and marine renewables remains that collected in Strangford Narrows in Northern Ireland where a long term study of seal populations and seal foraging movements has been carried out during the development and deployment stage of SeaGen, a large twin rotor tidal turbine. Telemetry data shows harbour seals used Strangford Narrows throughout periods of turbine operation and SeaGen is not an overt barrier to their movements. Research that will improve assessment of the possible impact of marine renewables on seal populations is urgently required. It is too early to suggest the most effective possible mitigation measures.

Climate change

At present, there is no evidence for impacts of climate change on harbour or grey seals in UK waters. However, impacts are more likely to be through changes in prey and no practical measures are likely to be able to alleviate such impacts.

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 2013. It begins with some general information on British seals, gives information on their current status, and addresses specific questions raised by the Marine Scotland (MS) and the Department of the Environment, Food and Rural Affairs (Defra) and Natural Resources Wales.

Appended to the main report are briefing papers which provide additional scientific background for the advice.

As with most publicly funded bodies in the UK, SMRU's long-term funding prospects involve a reduction in spending in cash terms that represents a substantial reduction in real terms into the foreseeable future. This reduction continues to have a negative impact on the underpinning scientific information on which this advice is based.

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 occasionally occur in UK coastal waters, including ringed seals (*Phoca hispida*), harp seals (*Phoca groenlandica*), bearded seals (*Erignathus barbatus*) and hooded seals (*Cystophora crystata*) all of which are Arctic species.

Grey seals

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

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

There are two centres of grey seal abundance in the North Atlantic; one in Canada and the north-east USA, centred on Nova Scotia and the Gulf of St Lawrence and the other around the coast of the UK especially in Scottish coastal waters. Populations in Canada, the USA, the UK and the Baltic 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. However, there are clear indications of a slowing down in population growth in the UK and Canadian populations in recent years.

Approximately 38% of the world's grey seals breed in the UK and 88% of these breed at colonies in Scotland with the main concentrations in the Outer Hebrides and in Orkney. There are also breeding colonies in Shetland, on the north and east coasts of mainland Britain and in SW England and Wales. Although the number of pups throughout Britain has grown steadily since the 1960s when records began, there is clear evidence that the population growth is levelling off in all areas except the central and southern North Sea where growth rates remain high. The numbers born in the Hebrides have remained approximately constant since 1992 and growth has been levelling off in Orkney since the late 1990s.

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 general grey seals are highly sensitive to disturbance by humans hence their preference for remote breeding sites. However, at one UK mainland colony at Donna Nook in Lincolnshire, seals have become habituated to human disturbance and over 70,000 people visit this colony during the breeding season with no apparent impact on the breeding seals.

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

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

Harbour seals

Adult harbour seals typically weigh 80-100 kg. Males are slightly larger than females. Like grey seals, harbour seals are long-lived with individuals living up to 20-30 years.

Harbour seals normally feed within 40-50 km around their haul out sites. They take a wide variety of prey including sandeels, gadoids, herring and sprat, flatfish, octopus and squid. Diet varies seasonally and from region to region. Because of their smaller size, harbour seals eat less food than grey seals; 3-5 kg per seal per day depending on the prey species.

Harbour seals come ashore in sheltered waters, typically 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 and can swim almost immediately.

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

Approximately 30% of European harbour seals are found in the UK; this proportion has declined from approximately 40% in 2002. 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, Firth of Tay and the Moray Firth. Scotland holds approximately 79% of the UK harbour seal population, with 16% in England and 5% in Northern Ireland.

The population along the east coast of England (mainly in The Wash) was reduced by 52% following the 1988 phocine distemper virus (PDV) epidemic. A second epidemic in 2002 resulted in a decline of 22% in The Wash, but had limited impact elsewhere in Britain. Counts in the Wash and eastern England did not demonstrate any recovery from the 2002 epidemic until 2009 but have increased dramatically in the past three years. In contrast, the adjacent European colonies in the Wadden Sea have experienced continuous rapid growth since 2002 but that increase may be slowing.

Major declines have now been documented in several harbour seal populations around Scotland, with declines since 2000 of 75% in Orkney, 30% in Shetland, and 85% in the Firth of Tay. However the pattern of declines is not universal. The Moray Firth count declined by 50% before 2005 remained reasonably stable for 4 years then increased by 40% in 2010 and fell again by 30% in 2011 and now appears stable. The Outer Hebrides apparently declined by 35% between 1996 and 2008 but the 2011 count was >50% higher than the 2008 count. The recorded declines are not thought to have been linked to the 2002 PDV epidemic that seems to have had little effect on harbour seals in Scotland.

Historical status

We have little information on the historical status of seals in UK waters. Remains have been found in some of the earliest human settlements in Scotland and they were routinely harvested for meat, skins and oil until the early 1900s. There are no reliable records of historical population size. Harbour seals were heavily exploited mainly for pup skins until the early 1970s in Shetland and The Wash. Grey seal pups were taken in Orkney until the early 1980s, partly for commercial exploitation and partly as a population control measure. Large scale culls of grey seals in the North Sea, Orkney and Hebrides were carried out in the 1960s and 1970s as population control measures.

Grey seal pup production monitoring started in the late 1950s and early 1960s and numbers have increased consistently since. However, in recent years, there has been a significant reduction in the rate of increase.

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

Legislation protecting seals

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

The Conservation of Seals Act prohibits taking seals during a close season (01/09 to 31/12 for grey seals and 01/06 to 31/08 for harbour seals) except under licence issued by the Marine Management Organisation (MMO). The Act also allows for specific Conservation Orders to extend the close season to protect vulnerable populations. After consultation with NERC, three such orders were established providing year round protection to grey and harbour seals on the east coast of England and in the Moray Firth and to harbour seals in the Outer Hebrides, Shetland, Orkney and the east coast of Scotland between Stonehaven and Dunbar (effectively protecting all the main concentrations of harbour seals along the east coasts of Scotland and England). The conservation orders in Scotland have been maintained under the Marine (Scotland) Act 2010.

The Marine (Scotland) Act 2010 (Section 6) prohibits the taking of seals except under licence. Licences can be granted for the protection of fisheries, for scientific and welfare reasons and for the protection of aquaculture activities. In addition, in Scotland it is now an offence to disturb seals at designated haulout sites. NERC (through SMRU) provides advice on all licence applications and haulout designations.

The Wildlife (Northern Ireland) Order 1985 provides complete protection for both grey and harbour seals and prohibits the killing of seals except under licence. In Northern Ireland it is an offence to intentionally or recklessly disturb seals at any haulout site.

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 SAC reporting cycle required formal status assessments for these sites and these were completed in 2013.

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

Questions for SCOS 2013 were received from all three 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 therefore 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.

In addition, Defra listed a number of secondary questions and asked if there was any additional information to *add* to the answers given in SCOS 2012. These are also listed under the relevant sections and, where appropriate, have been combined with similar questions from the other administrations. Where no new information is available, a summary of the current state of knowledge is shown in a text box.

Population dynamics

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

Current status of British grey seals

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. Thus, regional differences in numbers do not reflect the abundance of animals in each region that might be observed at other times of the year.

Due to a change in the air survey methods in 2012, which resulted in an increased number of photographs and a delay in providing the 2012 estimate, the most recent complete UK grey seal pup production estimate remains the 2010 estimate which was 50,200 (95% CI 47,500-52,900). Pup production estimates by location are given in Table 1.

To estimate the total population size in 2012, the population dynamics model trajectories were projected forward to give an estimate of 112,300 (95% CI 90,600-142,900) UK grey seals.

Table 1. ***Grey seal pup production estimates for the main colonies surveyed in 2010***.

Location	Pup production in 2010
England	**4,315**
Wales	**1,650**
Scotland	**44,138**
Northern Ireland	**100**
Total UK	**50,203**

Aerial surveys to estimate grey seal pup production were carried out in Scotland in 2012, using a new digital camera system. Details of the methods are given in SCOS-BP 13/01. The new camera generated approximately 20,000 photographs to process and count due to the smaller area covered by each digital image. Owing to the time required to optimise the system for handling and processing the images, only the counts in two regions (the Firth of Forth and Inner Hebrides, SCOS-BP 13/01) have been completed, so a 2012 overall pup production estimate is not yet available. However, in addition to the two regions mentioned above, 2012 estimates are available for colonies where ground counts are carried out (Donna Nook, Farne Islands and East Anglia).

Pup Production

Information on pup production at all major Scottish colonies has not been updated since SCOS 2011 and the details in SCOS–BP 11/01 are the most recent data available. The total number of pups born in 2010 at all annually surveyed UK colonies was estimated to be 44,900 (95% CI 44,226-44,522).

Regional estimates at annually surveyed colonies were 3,400 (95% CI 3,337-3,445) in the Inner Hebrides, 12,900 (95% CI 12,703-13,011) in the Outer Hebrides, 20,300 (95% CI 20,068-20,556) in Orkney and 8,300 (95% CI 8,177-8,451) at North Sea colonies (including Isle of May, Fast Castle, Farne Islands, Donna Nook, Blakeney Point and Horsey/Winterton). A further 5,300 pups were estimated to have been born at other scattered colonies throughout Scotland, Northern Ireland, South-west England and Wales, producing a total UK pup production of 50,200 (approximate 95% CI 49,500-50,850).

Information on 2012 pup production at UK colonies is currently only available for the southern North Sea, the Firth of Forth and the Inner Hebrides (Table 2 and SCOS-BP 13/01). Digital photographs for the remaining Scottish colonies are currently being analysed and once completed will provide a new estimate of total pup production from Scottish colonies. Colonies on the east coast of England are monitored by the National Trust, Lincolnshire Trust for Natural History and Natural England. Numbers of pups born at these colonies continued to increase rapidly, colonies in the southern North Sea increased by 15% between 2010 and 2011 and by 22% between 2010 and 2012. The English North Sea colonies represent only a proportion of the overall North Sea population so we cannot yet update the North Sea trajectory after 2010. However, the continued rapid increase at this subset of colonies does not suggest a change in the recent trends.

Trends in pup production

Details of the *trends* in pup production up to 2010 were presented in SCOS 2011 and in SCOS-BP 11/01. Briefly, this showed that there has been a continual increase in pup production since regular surveys began in the 1960s (Figure 1). In both the Inner and Outer Hebrides, the rate of increase declined in the early 1990s and production has been relatively constant since the mid-1990s. Although 2012 data for the Outer Hebrides are not yet available, data from the Inner Hebrides show an increase in pup production of 18.8%, the first substantial increase since the 1990s. And although the rate of increase in Orkney has declined since 2000, pup production continues to increase gradually.

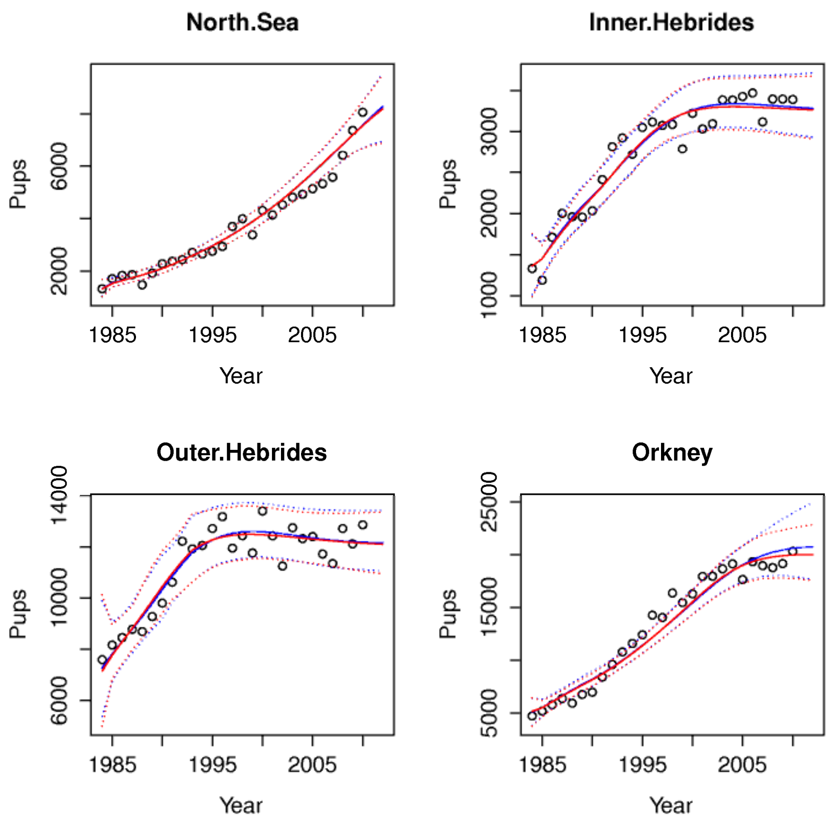

Figure 1. ***Mean estimates of pup production (solid lines) and 95%Confidence Intervals (dashed lines) from the model of grey seal population dynamics, fit to pup production estimates from 1984-2010 (circles) and a total population estimate from 2008.*** *Blue lines show the fit to pup production estimates alone; red lines show the fit to pup production estimates plus the total population estimate.*

Pup production at colonies in the North Sea continues to increase exponentially. The increase has apparently slowed at the Farne Islands, but there is 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 never previously bred in significant numbers. Pup production in 2010, and for those colonies where data are available for 2012, are shown in Table 2. Pup counts for 2012 are available for the major breeding sites in England (Donna Nook and East Anglia and the Farne Islands). Both show an increase compared to 2011 with Donna Nook and East Anglia up by ~14% and the Farne Islands by ~3%.

The most recent data for pup production in Wales remains the estimates for north Wales 2001-2002[1] at 110 pups, for Pembrokeshire 297 pups in 2005[2] and 260 pups born on Skomer Island in southeast Wales in 2011[3].

Table 2. ***Grey seal pup production estimates for the main colonies surveyed in 2010*** *and available 2012 grey seal pup production estimates compared to UK wide estimates for 2010.*

Location	Pup production in 2012	Average annual change from 2010 to 2012	Pup production in 2010	Average annual change in pup production from 2005 to 2010
Inner Hebrides	4,027	+9.0%	3,391	-0.0%
Outer Hebrides			12,857	+1.0%
Orkney			20,312	+2.4%
Firth of Forth	5,175	+10.0%	4,279	+9.0%
All other Scottish colonies (incl. Shetland & mainland)			3,299[1]	
Total Scotland			**44,138**	**+1.9%**
Donna Nook + East Anglia	3,359	+14.4%	2,566	+15.0%
Farne Islands	1,603	+3.4%	1,499	+5.9%
SW England (last surveyed 1994)			250	
Total England			**4,315**	
Total Wales [2]			**1,650**	
Total England & Wales			**5,965**	**+6.7%**
Northern Ireland			100	
Total (UK)			**50,203**	**+2.4%**

[1]Estimate derived from data collected in different years
[2]Estimate from indicator sites in 2004-05, multiplier derived from 1994 synoptic surveys

[1] http://biosciences.exeter.ac.uk/media/universityofexeter/schoolofbiosciences/pdfs/pgrstudentpublications/CCW_MMR_NO05.pdf
[2] Strong P.G., Lerwill J., Morris S.R., and Stringell, T.B. (2006) Pembrokeshire marine SAC grey seal monitoring 2005. CCW Marine Monitoring Report No: 26; unabridged version (restricted under licence). 54pp.
[3] http://wtswwcdn.8a1bc20d.cdn.memsites.com/wp-content/uploads/2011/05/2011-Skomer-Seal-Report-final.pdf

Population size

Converting pup counts from air surveys into a total population size requires a number of steps as shown in Figure 2.

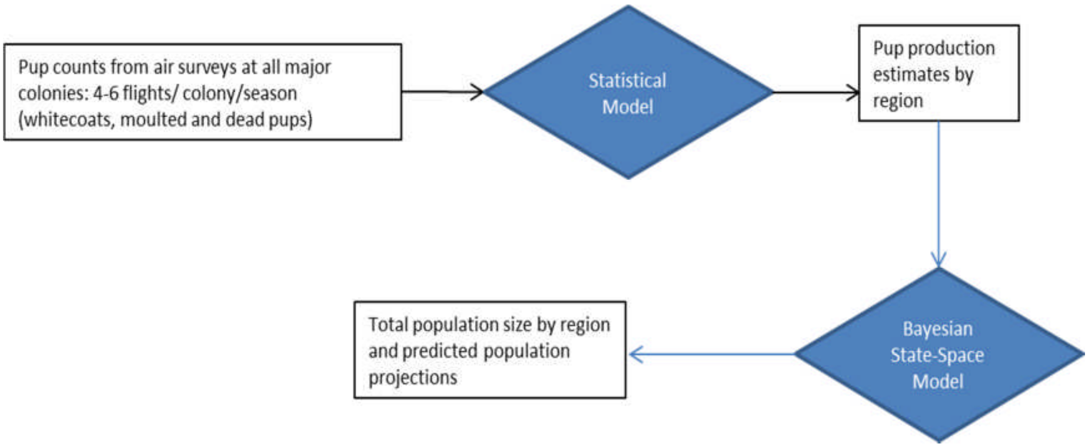

Figure 2. ***Schematic diagram of steps involved in estimating total population size from pup counts*** *(see also SCOS BP-09/02, SCOS BP-10/02).*

Thus, using appropriate estimates of age-specific fecundity rates and both pup and non-pup survival rates we can convert pup production estimates into estimates of total population size using a population dynamics, Bayesian state-space model. However, the estimate of total population alive at the start of the breeding season depends critically on the estimates of these rates.

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 or adults (SCOS-BP 09/02, 10/02 and 11/02) has resulted in reduced population growth rates in the Northern and Western Isles. Fitting the model of grey seal population dynamics with density dependence acting through either fecundity or pup survival showed that the time series of pup production estimates does not contain sufficient information to allow us to quantify the relative contributions of these factors (SCOS-BP 06/07, 09/02). In 2010 and 2011, we incorporated additional information in the form of an independent estimate of population size based on counts of the numbers of grey seals hauled out during the summer and information on their haulout behaviour (SCOS-BP 10/04 and 11/06).

In 2012, SCOS discussed the priors on the model input parameters in some detail, following re-examination of the data being used and the difference changing a number of them to less informative priors made to the population estimates (SCOS-BP 12/01 and SCOS-BP 12/02). Work on updating and finalising the priors is still in progress. However, the model has now been projected one year forward using the same priors as used in the previous analysis detailed in SCOS-BP 12/01 to provide the 2012 estimate. The estimated population size associated with all annually monitored colonies was 100,300 (95% CI 80,700-128,100) for the model incorporating the independent estimate (details of this analysis are given in SCOS BP 13/02). A comprehensive survey of data available from the less frequently monitored colonies was presented in SCOS BP 11/01. Total pup production at these sites was estimated to be approximately 5,300 in 2012. The total population associated with these sites was estimated using the average ratio of pup production to population size for all annually monitored sites. This ratio was based on the estimated population size derived from the pup survival model. Confidence intervals were estimated by assuming that they were proportionally similar to the pup-survival model confidence intervals. This produced a population estimate for these sites of 12,000 (approximate 95% CI 9,900 to 14,800). Combining this with the annually monitored sites gives an estimated 2012 UK grey seal population of 112,300 (95% CI 90,600-142,900). In addition, a sensitivity analysis is currently being carried out to investigate the relative importance of the prior distributions to the resulting population estimates. This will include determining how using the fecundity and survival rates from the long term studies on North Rona and the Isle of May would affect the relevant regional population estimates. These results will be available at SCOS 2014.

Population trends

The independent population estimate suggests that density dependence is acting mainly on pup survival. This also implies that the overall population will closely track the pup production estimates when experiencing density dependent control as well as during exponential growth. It is therefore likely that the total populations of grey seals in the Hebrides and Orkney will have followed similar trajectories to those shown by the time series of pup productions while the North Sea population is thought to still be growing exponentially. Further details on this trend are given in SCOS-BP 13/01.

UK grey seal population in a world context

The UK grey seal population represents approximately 38% of the world population on the basis of pup production. The other major populations in the Baltic and the western Atlantic are also increasing, but at a faster rate than in the UK (Table 3). If the difference in growth rate is due to reduced pup survival in the UK population compared to the Baltic and the western Atlantic, the UK will hold less than 38% of the total all age population.

Table 3. ***Relative sizes of grey seal populations****. Pup production estimates are generally used because of the uncertainty in overall population estimates*

Region	Pup Production	Year	Possible population trend[2]
UK	**50,200**	2010	Increasing
Ireland	1,600	2005	Unknown[1]
Wadden Sea	430	2012[3]	Increasing [2]
Norway	1,300	2008	Increasing[4]
Russia	800	1994	Unknown[2]
Iceland	1,200	2002	Declining[2]
Baltic	4,700	2007	Increasing[2,5]
Europe excluding UK	**10,030**		Increasing
Canada - Sable Island	62,000	2010	Increasing[6]
Canada - Gulf St Lawrence + Eastern Shore Canada	14,200	2010	Declining[7]
USA	2,600	2008	Increasing[8]
WORLD TOTAL	**129,000**		Increasing

[1] Ó Cadhla, O., Strong, D., O'Keeffe, C., Coleman, M., Cronin, M., Duck, C., Murray, T., Dower, P., Nairn, R., Murphy, P., Smiddy, P., Saich, C., Lyons, D. & Hiby, A.R. 2007. An assessment of the breeding population of grey seals in the Republic of Ireland, 2005. Irish Wildlife Manuals No. 34. National Parks & Wildlife Service, Department of the Environment, Heritage and Local Government, Dublin, Ireland.
[2]Data summarised in:- Grey seals of the North Atlantic and the Baltic. 2007. Eds: T. Haug, M. Hammill & D. Olafsdottir. NAMMCO Scientific Publications, Vol. 6.
[3] Brasseur, S., Borchardt, T., Czeck, R., Jensen, L.F., Galatius, A., Ramdohr, S., Siebert, U., Teilmann, J., 2012, Aerial surveys of Grey Seals in the Wadden Sea in the season of 2011-2012 - Increase in Wadden Sea grey seals continued in 2012. Trilateral Seal Expert Group.
[4] Øigård, T.A., Frie, A.K., Nilssen, K.T., Hammill, M.O., 2012, Modelling the abundance of grey seals (*Halichoerus grypus*) along the Norwegian coast. ICES Journal of Marine Science: Journal du Conseil, 69(8) 1436-1447.
[5] Baltic pup production estimate based on mark recapture estimate of total population size and an assumed multiplier of 4.7 HELCOM fact sheets (www.HELCOM.fi)
[6] Bowen, W.D., McMillan,J.I. & Blanchard, W. 2007. Reduced Population Growth Of Gray Seals At Sable Island: Evidence From Pup Production And Age Of Primiparity. Marine Mammal Science, 23(1): 48–64
[7] Thomas,L.,Hammill,M.O. & Bowen,W.D. 2011 Estimated size of the Northwest Atlantic grey seal population 1977-2010 Canadian Science Advisory Secretariat: Research Document 2011/17 pp27.
[8]NOAA (2009) http://www.nefsc.noaa.gov/publications/tm/tm219/184_GRSE.pdf

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.

Combining the most recent counts (2007-2012) gives a total of 26,836 counted in the UK. Scaling this by the estimated proportion hauled out produced an estimated total population of UK in 2012 of 37,300 (approximate 95% CI 30,500 – 49,700).

Harbour seal counts were stable or increasing until around 2000 when declines were seen in Shetland (which has declined by 30% since 2000), Orkney (down 75% since 2000) and the Firth of Tay (down 85% since 2000). However, other regions are now stable following a period of decline (the Moray Firth) and some have been largely continually stable (west coast of Highland region and the Outer Hebrides). By contrast, counts along the English east coast were 18% higher than in 2011 and are now above the pre-2002 phocine distemper virus (PDV) epidemic.

The most recent minimum population estimates by region are given in Table 4.

Table 4. ***Minimum estimates of the UK harbour seal populations.***

Location	Most recent count (2007-2012)
England	4,568
Wales	0[1]
Scotland	21,320
Northern Ireland	948
Total UK	**26,836**

[1] There are no established harbour seal haul out sites in Wales

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 13/03. Given length of coastline it is impractical to survey the whole coastline every year and SMRU aims to survey the whole coastline across 5 consecutive years. However, in response to the observed declines around the UK the survey effort has been increased. The majority of the English and Scottish east coast populations are surveyed annually.

Seals spend the largest proportion of their time on land during the moult and they are therefore visible during this period to be counted in the surveys. Most regions are surveyed by a method using thermographic aerial photography 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. We cannot be certain what this proportion is, but it is known to vary in relation to factors such as the time of year, the state of the tide and the weather. Efforts are made to reduce the effect of these factors by standardising the time of year and weather conditions and always conducting surveys within 2 hours of low tide.

The most recent counts of harbour seals by region are given in Table 5 and Figure 3. These are minimum estimates of the British harbour seal population. Results of surveys conducted in 2012 are described in more detail in SCOS-BP 13/03. It has not been possible to conduct a synoptic survey of the entire UK coast in any one year. Data from different years have therefore been grouped into recent, previous and earlier counts to illustrate, and allow comparison of, the general trends across regions.

Combining the most recent counts (2007-2012) at all sites, approximately 26,840 harbour seals were counted in the UK: 80% in Scotland; 15% in England; 5% in Northern Ireland (Table 5). Including the 2,900 seals counted in the Republic of Ireland produces a total count of 29,790 harbour seals for the British Islands.

Apart from the population in The Wash, harbour seal populations in the UK were relatively unaffected by PDV in 1988. The overall effect of the 2002 PDV epidemic on the UK population was even less pronounced. However, again the English east coast populations were most affected. Counts from 2002 to 2008 did not indicate a recovery in The Wash population following the epidemic. From 2008 to 2010 the counts increased by around 40%. The 2012 count was 18% higher than in 2011, taking the number counted above the pre-2002 epidemic count.

The 2012 pup and adult counts were 33% and 8% higher respectively than the 2011 counts, and similar to those from 2010. Estimated peak pup counts have increased at an average rate of 9% p.a. since 2003 although there is considerable inter-annual variation (SCOS BP 13/03).

Table 5. ***Minimum estimates of the UK harbour seal population in Management Areas from the most recent and from two previous surveys****. These are the numbers of seals counted in aerial surveys with the survey year below the number of seals counted. A new count for the Republic of Ireland will be available shortly.*

Harbour seal Management Area count	**Most recent** **(2007-2012)**	**2000-2005**	**1996-1997**
Shetland (includes Foula from 2006)	3,039 2009	4,883 2001	5,991 1997
Orkney & North Coast	2,799 2008,10	7,926 2001,05	8,788 1997
Outer Hebrides	2,739 2011	2,067 2003	2,820 1996
West Scotland	10,611 2007,8,9	11,668 2000,5	8,811 1996,7
South-west Scotland	834 2007	623 2005	929 1996
East Scotland	326 2007,12	686 2005	764 1997
Moray Firth	972 2007,11,12	959 2005	1429 1997
TOTAL SCOTLAND	**21,320**	**28,812**	**29,532**
North-east England	70 2007,12	52 1994, 2005	47 1994,7
South-east England	4,568 2012	3,234 2005	3,178 1997
West England & Wales (estimated)	20	20	15
TOTAL ENGLAND	**4,568**	**3,306**	**3,240**
TOTAL BRITAIN	**25,888**	**32,118**	**32,772**
TOTAL NORTHERN IRELAND	**948** **2011**	**1,267** **2002**	
TOTAL BRITAIN & N. IRELAND	**26,836**	**33,385**	
TOTAL REPUBLIC OF IRELAND	**2,955** **2003**	**2,955** **2003**	
TOTAL GREAT BRITAIN & IRELAND	**29,791**	**36,340**	

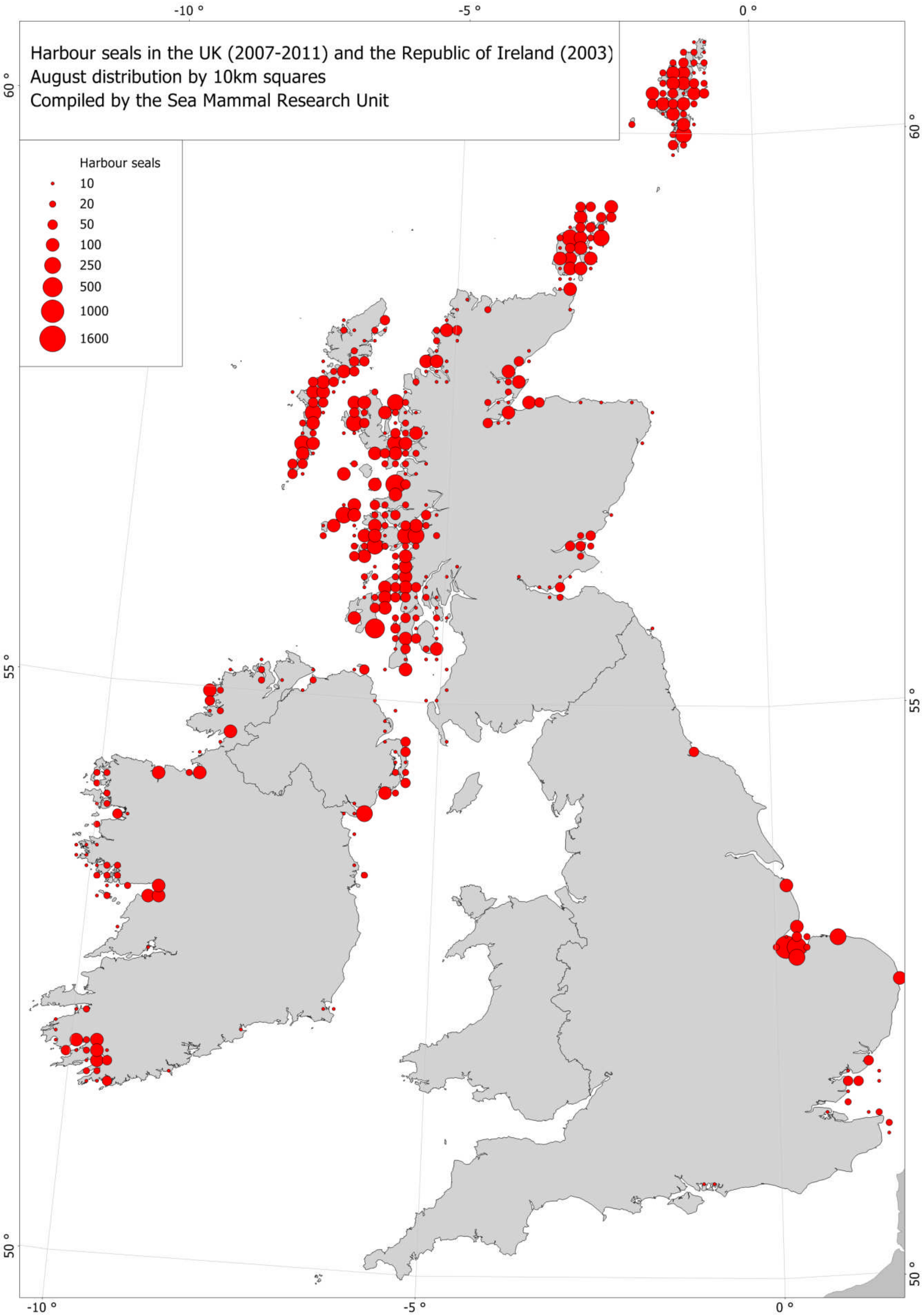

Figure 3. ***The August distribution of harbour seals in UK and Ireland, by 10km squares.*** *These data are from surveys carried out between 2007 and 2011 in UK and 2003 in the Republic of Ireland*

Population trends

As reported in SCOS 2008 to 2012, there have been general declines in counts of harbour seals in several regions around Scotland. A summary of the overall trends and the estimated proportional changes in UK harbour seal counts between 2000 and 2010 are given in Figure 4. This represents the 10 year time period during which the major declines in abundance have been observed (SCOS-BP13/03).

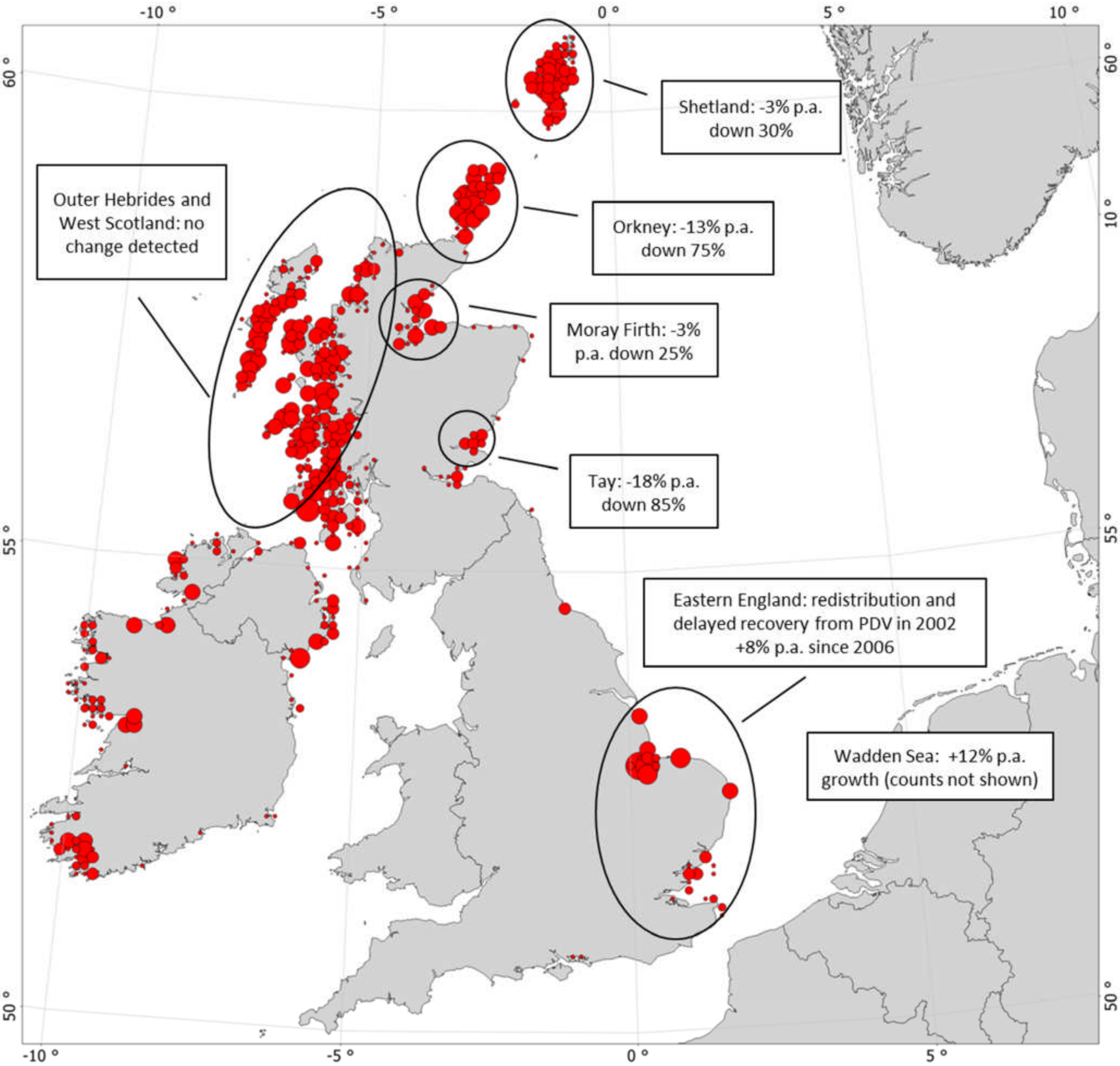

Figure 4. ***Recent trends in numbers of harbour seals counted in different parts of UK****. Both the trends and the proportional change are estimated between 2000 and 2010 using generalised linear models following the methods in Lonergan et al., (2007[4]). The information for the Wadden Sea is provided for comparison from Reijnders et al., (2010[5]).*

[4] Lonergan, M., C. D. Duck, et al. (2007). Using sparse survey data to investigate the declining abundance of British harbour seals. Journal of Zoology, 271(3), 261-269.

[5] Reijnders, P. J. H., S. M. J. M. Brasseur, et al. (2010). Population development and status of harbour seals (*Phoca vitulina*) in theWadden Sea. NAMMCO Scientific Publications, 8: 95-106

Due to poor weather conditions only part of Orkney was surveyed in 2012. Therefore to avoid confusion in reporting numbers, these have not been included in this years' report (SCOS-BP 13/03). The most recent complete survey of Orkney in 2010 counted 6.2% fewer seals than during the previous complete count in 2008. The Orkney harbour seal population has declined by 75% since 2000 and has been falling at an average rate of 13% p.a. The 2010 counts may indicate a slowing down of the rate of decline, with an average decrease of 3% pa. However, the counts for the sub regions that were completed in 2012, compared to the previous counts, show no signs of recovery. A projected time to extinction using a stochastic matrix population model suggests extinction of this population may occur around 2070 (95% CI: 2055-2095).

In contrast, the number of harbour seals counted in the Outer Hebrides in 2011 (2,739) was considerably higher (by 51.8%) than the previous complete Outer Hebrides count in 2008 (1,804). This was the second highest count of harbour seals in the Outer Hebrides since 1990. The status of the harbour seal population in the Outer Hebrides is unclear so until further information is available, SCOS recommends that the conservation in the Outer Hebrides order remain in place and that further monitoring be carried out.

In 2012, the Inner Moray Firth (Ardersier to Loch Fleet) count was 677, 30.0% lower than the high August 2010 count (975). This count was virtually identical to the 2011 count, continuing to support the suggestion that the long term decline in the Moray Firth population may have been halted.

The Firth of Tay count in 2012 was slightly higher than the very low 2011 count. This SAC population has declined at an average rate of 20% p.a. since 2002, 89% lower than the peak count in 2000. An analysis of the likely future trends in population in this population suggests that it could go extinct by 2040 and probably much sooner unless the causes of the additional mortality are removed.

UK harbour seal populations in a European context

The UK harbour seal population represents approximately 30% of the eastern Atlantic sub-species of harbour seal (Table 6). The declines in Scotland mean that the relative importance of the UK population will probably decline.

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	Possible population trend[2]
Outer Hebrides	2,700	2011	Uncertain
Scottish W coast	11,400	2007-2009	None detected
Scottish E & N coast	1,300	2011	Declining
Shetland	3,000	2009	Declining
Orkney	2,700	2010	Declining
Scotland	**21,300**		
England	**4,500**	2012	Increasing[3]
Northern Ireland	**950**	2011	Decrease since '70s
UK	**26,750**		
Ireland	2,900	2003	Unknown
Wadden Sea-Germany	15,700	2012	Increasing after 2002 epidemic
Wadden Sea-NL	6,500	2012	Decreasing
Wadden Sea-Denmark	4,000	2012	Increasing after 2002 epidemic
Lijmfjorden-Denmark	1,050	2008	Recent decline
Kattegat/Skagerrak	11,700	2007	Recent decline
West Baltic	750	2008	Increasing
East Baltic	600	2008	Increasing
Norway	6,700	2006	Declining
Iceland	11,000	2011	Stable
Barents Sea	1,900	2010	Unknown
Europe excluding UK	**62,800**		
Total	**89,550**		

[1] –counts rounded to the nearest 100. They are minimum estimates of population size as they do not account for proportion at sea and in many cases are amalgamations of several surveys.
[2] – There is a high level of uncertainty attached to estimates of trends in most cases.
[3] – Declined as a result of the 2002 PDV epidemic but recent increase to pre-epidemic levels.
Data sources: ICES Report of the Working Group on Marine Mammal Ecology 2004; 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 harbor 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.; http://www.waddensea-worldheritage.org/news/2012-10-31-seal-count-2012-more-seals-ever-wadden-sea; http://www.fisheries.is/main-species/marine-mammals/stock-status/;
http://www.nefsc.noaa.gov/publications/tm/tm213/pdfs/F2009HASE.pdf
http://www.nammco.no/webcronize/images/Nammco/976.pdf

2. What is known about the population structure, including survival and age structure of grey and common seals in UK waters?	MS Q2; Defra Q2; NRW Q2

Grey seals

Whilst there is some information on the genetic differences between certain grey seal breeding colonies and limited empirical studies on the survivorship of grey seal pups during their first year of life, very little contemporary data exists on the age and population structure of UK grey seals. Information on vital rates would improve our ability to provide advice on population status.

Within Europe there are two genetically distinct groups, one that breeds in the Baltic, usually pupping on sea ice in the spring, and one that breeds outside the Baltic, usually pupping on land in Autumn and early winter. These populations appear to have been effectively demographically and evolutionarily isolated at least since the last Glacial Maximum[6]. The vast majority (90%) of European grey seals breeding outside the Baltic breed around Britain. On the basis of genetic differences there is a degree of population isolation between grey seals that breed in the south-west (Devon, Cornwall and Wales) and those breeding around Scotland[7] and within Scotland, there are significant genetic differences between grey seals breeding on the Isle of May and on North Rona[8]. Until 2002, SMRU treated this last group as a single population for the purpose of estimating total population size. Estimates of the numbers of seals associated with different regions were obtained by dividing up the total population in proportion to the number of pups born in each region. Interestingly this apparent structure in the UK population is not mirrored in the Canadian and USA population where a similar analysis concluded that the Gulf of St Lawrence, Sable Island and north-eastern US populations were not separable[9].

Since 2003, a spatially-explicit model has been used to estimate the British grey seal population from geographically structured pup production estimates. An application of this model (SCOS-BP 03/04) indicated that there was little movement of breeding animals between the Inner Hebrides, Outer Hebrides, Orkney and the North Sea. This suggestion is further supported by recent results from grey seal population models that indicate an absence of large scale redistribution of breeding females between regions (SCOS-BP 09/02 and 10/02).

It is however not clear how much power such studies have to detect movement of un-recruited females to other regions. Large scale movements of foraging seals into the North Sea are suggested by the rapidly increasing summer haulout counts and an analysis of movements between foraging sites and breeding sites based on satellite telemetry data[10]. The fact that this region is the only one showing continued rapid growth in pup production may indicate recruitment from adjacent populations. Further analysis of pup production data will be required to examine this hypothesis.

Age and sex structure

While the population was growing at a constant rate, i.e. a constant exponential change in pup production, the stable age structure for the female population could be calculated from the population dynamics model. However, since the mid-1990s this has not been possible since 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. The results of population estimation models incorporating an

[6] Boskovic, Kovacs,K.M., Hammill,M.O. & White,B.N. (1996) Geographic distribution of mitochondrial DNA haplotypes in grey seals (*Halichoerus grypus*) Canadian Journal of Zoology 74, 1787-1796

[7] Walton M. & Stanley, H.F. 1997. Population structure of some grey seal breeding colonies around the UK and Norway. European Research on Cetaceans. Proc 11th annual conference of European cetacean society. pp293-296

[8] Allen, P. J., W. Amos, et al. (1995). Microsatellite variation in grey seals (*Halichoerus grypus*) shows evidence of genetic differentiation between two British breeding colonies." Molecular Ecology 4(6), 653-662

[9] Wood, S. A., T. R. Frasier, et al. (2011). The genetics of recolonization: an analysis of the stock structure of grey seals (*Halichoerus grypus*) in the northwest Atlantic." Canadian Journal of Zoology, 89(6): 490-497

[10] Russell, D. J. , McConnell, B. J. , Thompson, D. , Duck, C. D. , Morris, C. , Harwood, J. & Matthiopoulos, J. (2013) Uncovering the links between foraging and breeding regions in a highly mobile mammal Journal of Applied Ecology. 50, 499-509.

independent population estimate (SCOS-BP 10/04) indicate that the density dependent effects are operating through reduced pup survival (SCOS-BP 10/02 and 11/02).

A consequence of a gradually increasing level of pup mortality would be a relative reduction in the size of young age classes. This density-dependent effect has been apparent since the mid-1990s in the Hebridean populations, implying that at least the youngest 15 to 20 year classes will be reduced. The effect is more recent in Orkney so fewer year classes will be reduced. In the North Sea, the continued exponential growth implies that there will have been little or no perturbation of the stable age structure.

Although there has never been any reliable information on age structure for the male component of the population, the fact that the independent estimate is well below the mean predicted population size from the pup-survival model may be an indication that male survival is low or has perhaps declined relative to female survival. To date, the male population has estimated by multiplying the female estimate by a fixed factor of 0.73. Sex-specific, mark-recapture estimates of survival for North Sea grey seal pups indicated that male survival rates were approximately a third of those for female pups during the first 6 months of independent foraging[11]. In the absence of differential mortality in older age classes, these observed differences in pup mortality would produce a scaling factor of 0.33 (SCOS-BP 12/02). However, a re-analysis of these data is currently being carried out and will be available for SCOS 2014. The age-structured population model therefore continues to use the fixed sex ratio of 1:0.73.

Survival and fecundity rates

Survival rates and fecundity estimates for adult females breeding at North Rona and the Isle of May have been estimated from re-sightings of permanently marked animals. An integrated analysis of resightings, post-partum mass and reproductive success data was used to explore the relationship between mass and probability of breeding (individual fecundity). Results suggest important differences between the Isle of May and North Rona. Adult survival at the Isle of May was not related to mass and was estimated to be generally high with low variance 0.950 (95% CI 0.933 - 0.965). At North Rona survival rates varied over time between 0.75 and 0.99. There was no evidence of mass dependent survival, but there was annual variation in mass gain at the Isle of May. Overall fecundity estimates differed between sites and fecundity declined rapidly with decreasing maternal mass at the end of a breeding episode. These estimates are lower than previous estimates for UK grey seals of 0.94 for the Farne Islands and 0.83 for the Hebrides[12].

The impact of using the apparent survival and fecundity rates from the long term, individual based studies to inform the priors for the regional estimation of total population size is currently being investigated.

The impact of a cut in the funding from NERC may mean a reduction in the ability of SMRU to carry out fieldwork on the Isle of May and North Rona on an annual basis and less reliable estimates of vital rates. An initial simulation study showed that reducing the time series to every two or three years produces reasonable, but less precise, estimates of female fecundity. However, survival estimates derived from such reduced field work were very different from those based from annual sampling, even when estimating a long-term (geometric) mean survival rate at a colony. Further analysis on the effect of different fieldwork scenarios will be available for SCOS 2014.

Harbour seals

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 moulting surveys. Information on vital rates would improve our ability to provide advice on population status.

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

[11] Hall, A.J., McConnell, B.J. and Barker, R.J. (2001) Factors affecting first-year survival in grey seals and their implications for life history strategy. Journal of Animal Ecology 70, 138-149.
[12] Boyd, I. L. (1985). Pregnancy and ovulation rates in grey seals (*Halichoerus grypus*) on the British coast. Journal of Zoology 205(A), 265-272.

found dead during the PDV epidemics in 1988 and 2002 were aged, these were clearly biased samples that cannot be used to generate population age structures.

Information on age and length of UK harbour seals are available from live captured animals between 1988 and 2012. Despite obtaining age estimates from teeth collected from over 500 seals, within regions the sample sizes were relatively small and unbalanced. However, both males and females from the east coast of Scotland and the Moray Firth were significantly shorter than elsewhere although there were no differences within regions before and after 2000, when the Scottish populations started to decline.

Model assumptions for the estimated time-to-extinction for the Tay and Eden SAC harbour seal population (SCOS-BP 12/04) were based on the premise that the sex ratio of the remaining population was 1:1 male to female. However, this is unlikely to be the case given the greater number of dead female harbour seals that have recently been reported. It is therefore important that a better estimate be obtained. This is currently underway in a study funded by Scottish Natural Heritage using DNA scat analysis from haulouts in the Tay, Eden and Firth of Forth. High resolution digital aerial photographs have also been collected to determine if animal size estimates could be obtained. These estimates, combined with regional age-length data from captures and controlling for time of year that may affect sex-specific haulout behaviour, may be combined to assist in determining the current sex ratio for this region.

Survival and fecundity rates

Survival estimates among adult UK harbour seals from photo-ID studies carried out in the Moray Firth have been published[13],[14]. This resulted in estimates of 0.97 (95% CI 0.9-0.99) for females and 0.89 (0.71-0.96) for males for the wider Moray Firth and 0.98 (95% CI 0.92-1.00) for both species in the Cromarty Firth.

A study investigating survival in first year harbour seal pups using telemetry tags was carried out by SMRU in Orkney and on Lismore in 2007. Survival was not significantly different between the two regions and expected survival to 200 days was very low at only 0.3[15].

3. Is there any [new] evidence of populations or subpopulations specific to local areas in UK waters?	MS Q2; Defra Q3; NRW Q3

There have been no specific developments in this area and therefore no new information to add.

Grey Seals

- Grey seals at all of the English North Sea breeding sites are considered to have been relatively recently derived from other North Sea colonies and as such are unlikely to show any significant differentiation. However, this North Sea group does show a degree of reproductive isolation from those breeding in the West England and Wales Management Unit.
- A study was carried out in 1996 to investigate population structure among grey seals at some colonies around the UK including samples from animals in the West England and Wales Management Unit[20]. One haplotype was only found in Cornwall and results suggested a difference between animals breeding in the West England and Wales Management Unit than elsewhere. As far as we are aware, this is the only study that has been carried out on breeding animals from this region.

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

[14] Cordes, L. 2011. Demography and breeding phenology of a marine top predator. PhD Thesis, Universityof Aberdeen, September 2011, pp190.

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

- Harbour SealsGenetic analysis suggests that there may be significant genetic differentiation between harbour seal populations in European waters[16],[17]. The Irish-Scottish, the English east coast and the Wadden Sea harbour seals were identified as distinct population units.

There have been no specific developments in this area and therefore no new information to add.

- Controlling seal populations could potentially be achieved by non-lethal reduction of the birth rate or by excluding seals from sensitive habitats and regions.
- Different forms of chemical sterilization are available and some are known to be effective in seals.
- Uncertainties surround the potential secondary effects of this type of intervention on colony structure, which could have the unintended consequences and actually stimulate population growth.
- Acoustic deterrent devices may be used to exclude seals from sensitive regions or act as barriers to upstream movements.

5. What are the latest results from satellite tagging in respect of usage of specific coast and marine areas around England by grey and common seals and whether or not these suggest potential foraging sites? And what is the latest information on seal movements (satellite tracking or photo ID) between colonies in Wales, the West England and Wales Management Unit, other regions in the UK, Ireland and France?	Defra Q6; NRW Q4

Refined, population scale, at–sea usage maps have been developed using the telemetry data obtained from both grey and harbour seals. These were presented in SCOS-BP 12/05 and are shown in Figures 5 and 6.

Grey seals

The latest information on the movements of adult grey seals tagged in Wales is summarised in the Atlas of the marine Mammals of Wales[18]. In addition, the movements of grey seals tagged (coded by management region) is shown in Figure 7a (adults) and 5b (pups). The tracks of the animals captured in the West England and Wales management unit are shown in black.

High resolution GPS/GSM mobile phone tags were attached to newly weaned grey seal pups at breeding sites at Anglesey, Bardsey and Ramsey Islands in Wales in 2009 and 2010. Typically, pups spent the first month or so in waters close to their breeding beaches, spending most of this time in tidal rapid areas. With time, animals travelled more widely, one ranging as far as the west of Brittany. In several cases however, seals found other high tidal current areas and appeared to drift and forage within these in a similar way. Pups from both Ramsey and Anglesey dispersed widely by the end of the study, with seals from both sites moving to south east Ireland and Cornwall.

Similar telemetry studies have been carried out with adult grey seals in France. Results indicate frequent movements between Brittany, Cornwall, Wales, Western Ireland and, in one case, South west Scotland (Cecile Vincent pers comm). Results from grey seals tagged in the Baie de Somme (eastern English Channel) indicate frequent movements between the French coast and haulout sites off Kent, East Anglia, Donna Nook and the Farne Islands and seals tagged at the Baie de Somme in the summer may have bred at sites in East Anglia and SE Scotland.

Additional information on grey seal movements and site fidelity in the West England and Wales Management unit is being collected by local wildlife and voluntary groups, particularly the Cornwall Seal

[16] Goodman, S.J. (1998). Patterns of extensive genetic differentiation and variation among European harbour seals (*Phoca vitulina vitulina*) revealed using microsatellite DNA polymorphisms. Molecular Biology and Evolution, 15, 104-118.
[17] Stanley, H.F., Casey S., et al. (1996). Worldwide patterns of mitrochondrial DNA differentiation in the harbour seal (*Phoca vitulina*). Molecular Biology and Evolution 13(2), 368-382.
[18] http://www.ccgc.gov.uk/landscape--wildlife/managing-land-and-sea/marine-mammal-atlas.aspx

group and the Cardigan Bay Marine Wildlife Centre[19]. An additional collaborative study carried out at SMRU investigated the connectivity between grey seal colonies in the southern Irish Sea. A summary of the findings are shown in Figure 8. In general the majority of the resightings were within the same area and the number of matches was proportional to the distances between the colonies, after controlling for effort. This work is continuing as part of a PhD CASE studentship jointly funded by Natural Resources, Wales.

[19] http://www.cornwallsealgroup.co.uk/

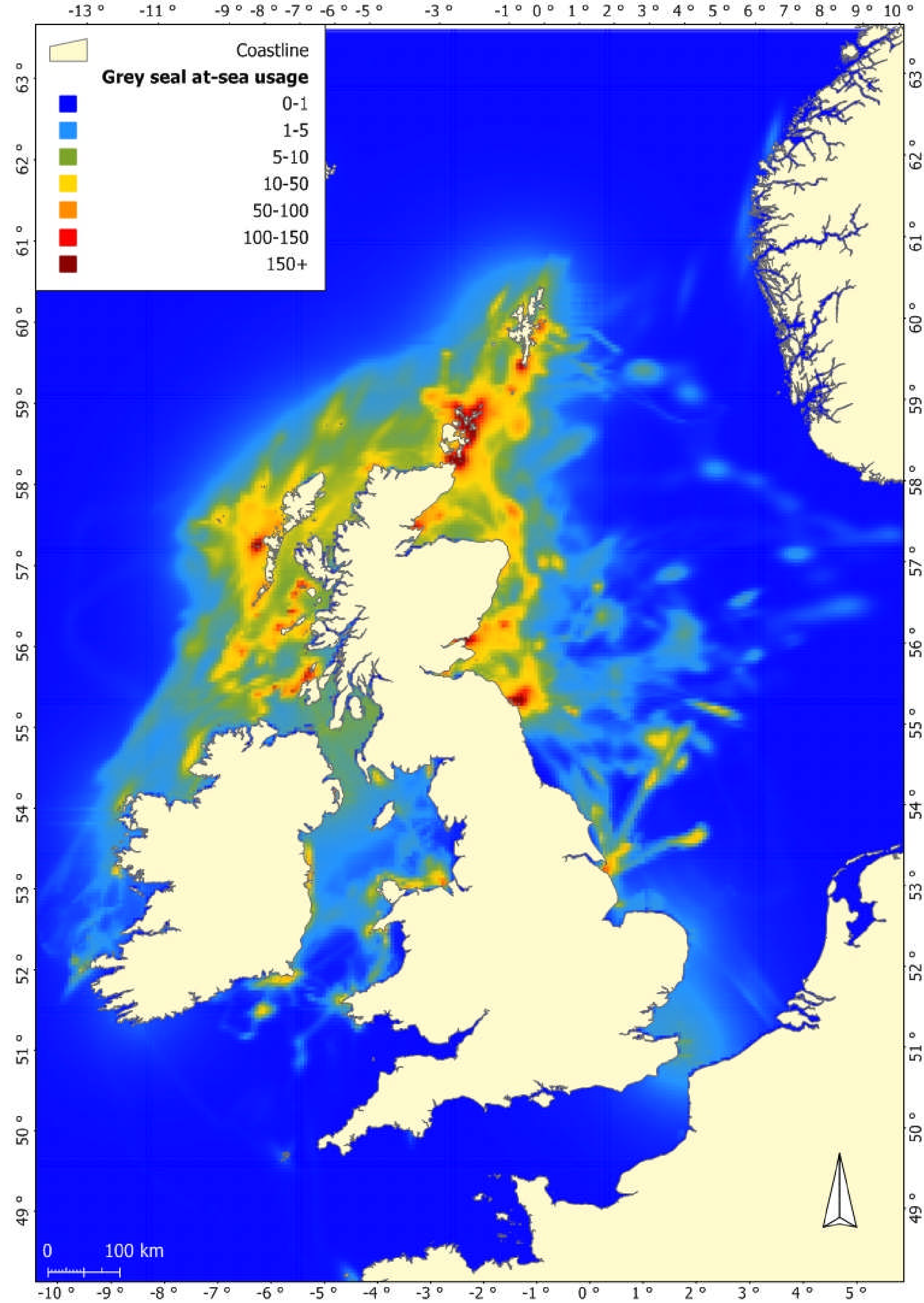

*Figure 5. **Estimated grey seal total (at-sea and hauled-out) usage around the UK.***

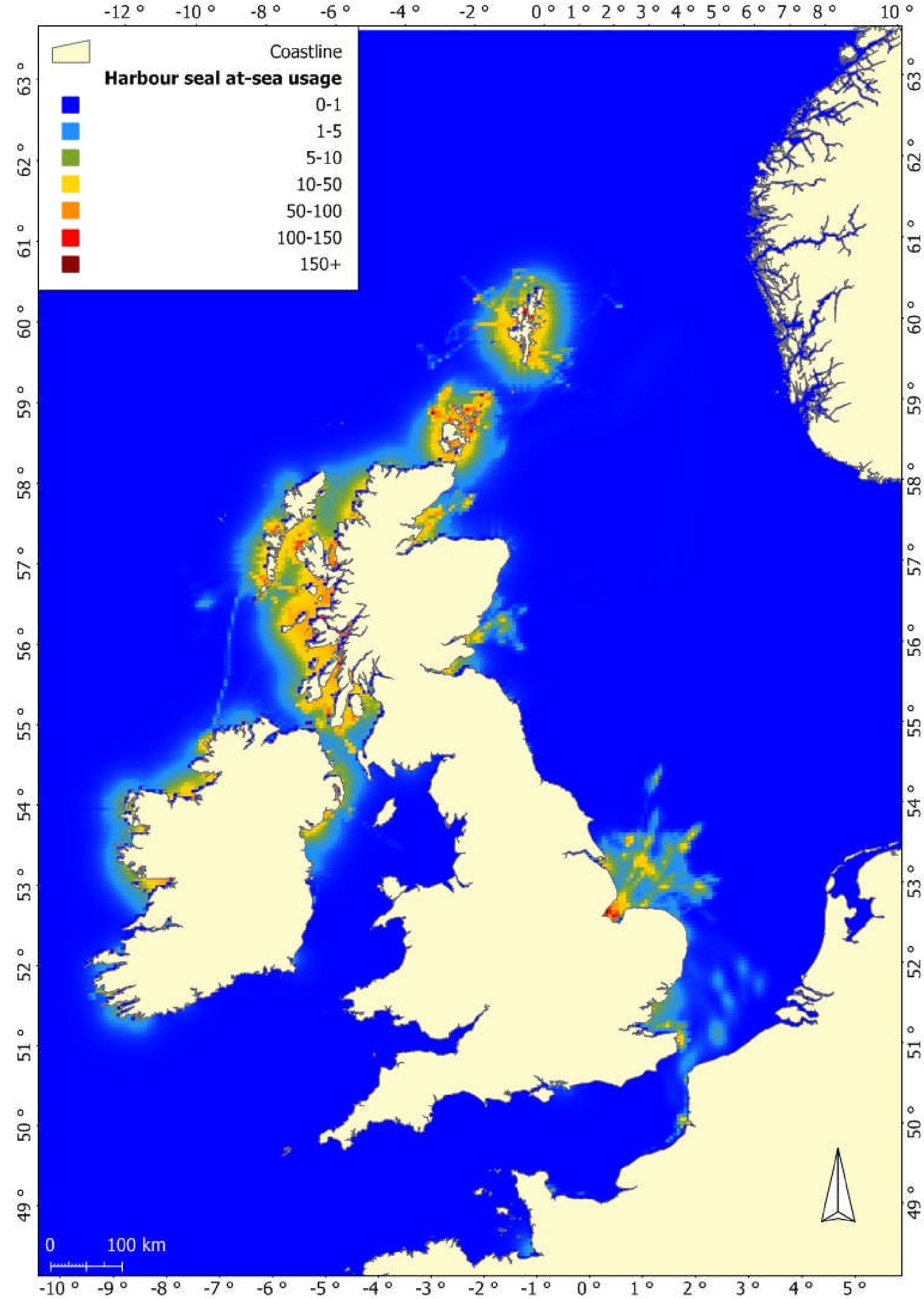

Figure 6. ***Estimated harbour seal total (at-sea and hauled-out) usage around the UK.***

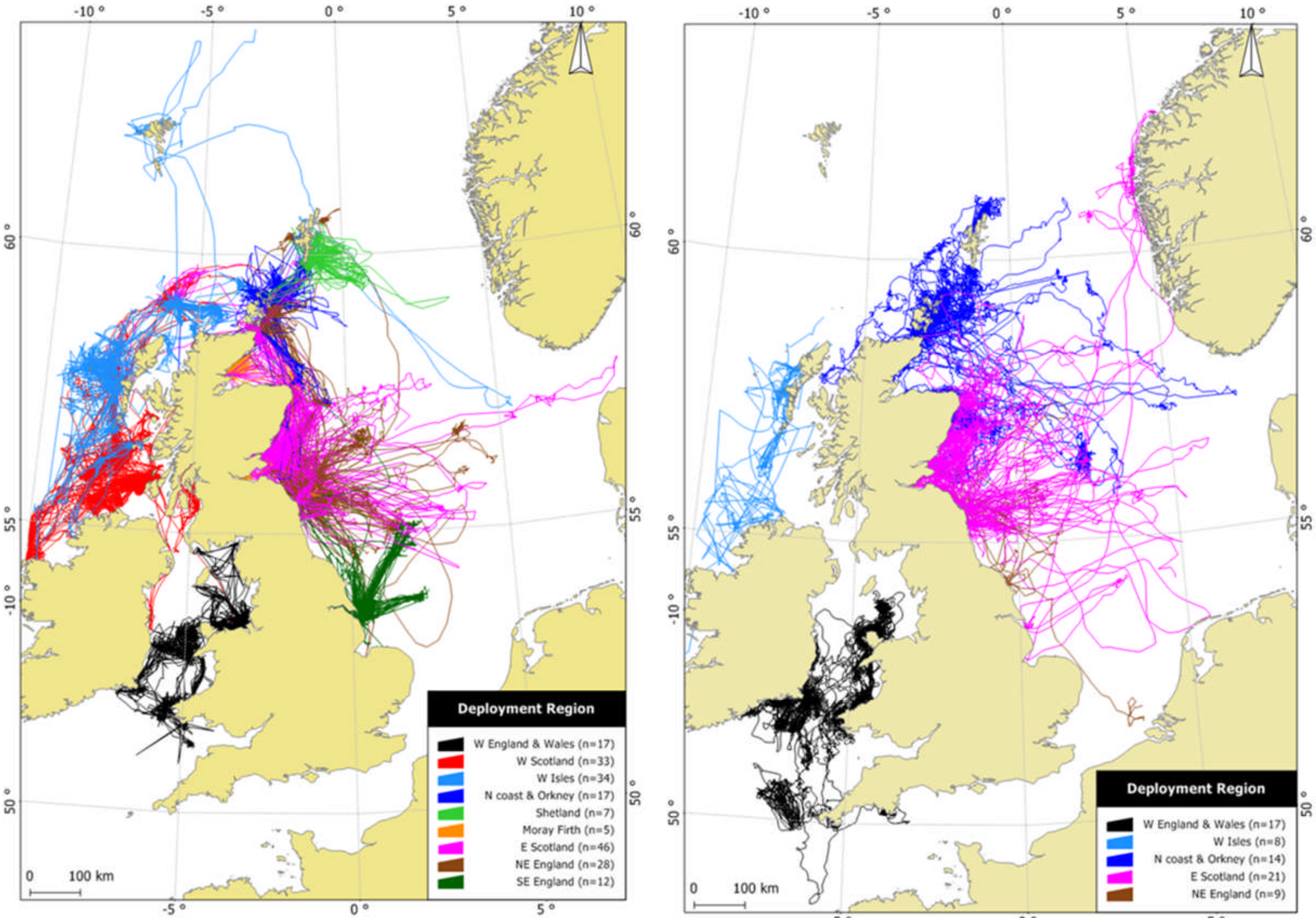

Figure 7. ***Tracks of grey seal (a) adults and (b) pups by deployment region (data collected between 1988 and 2012)***

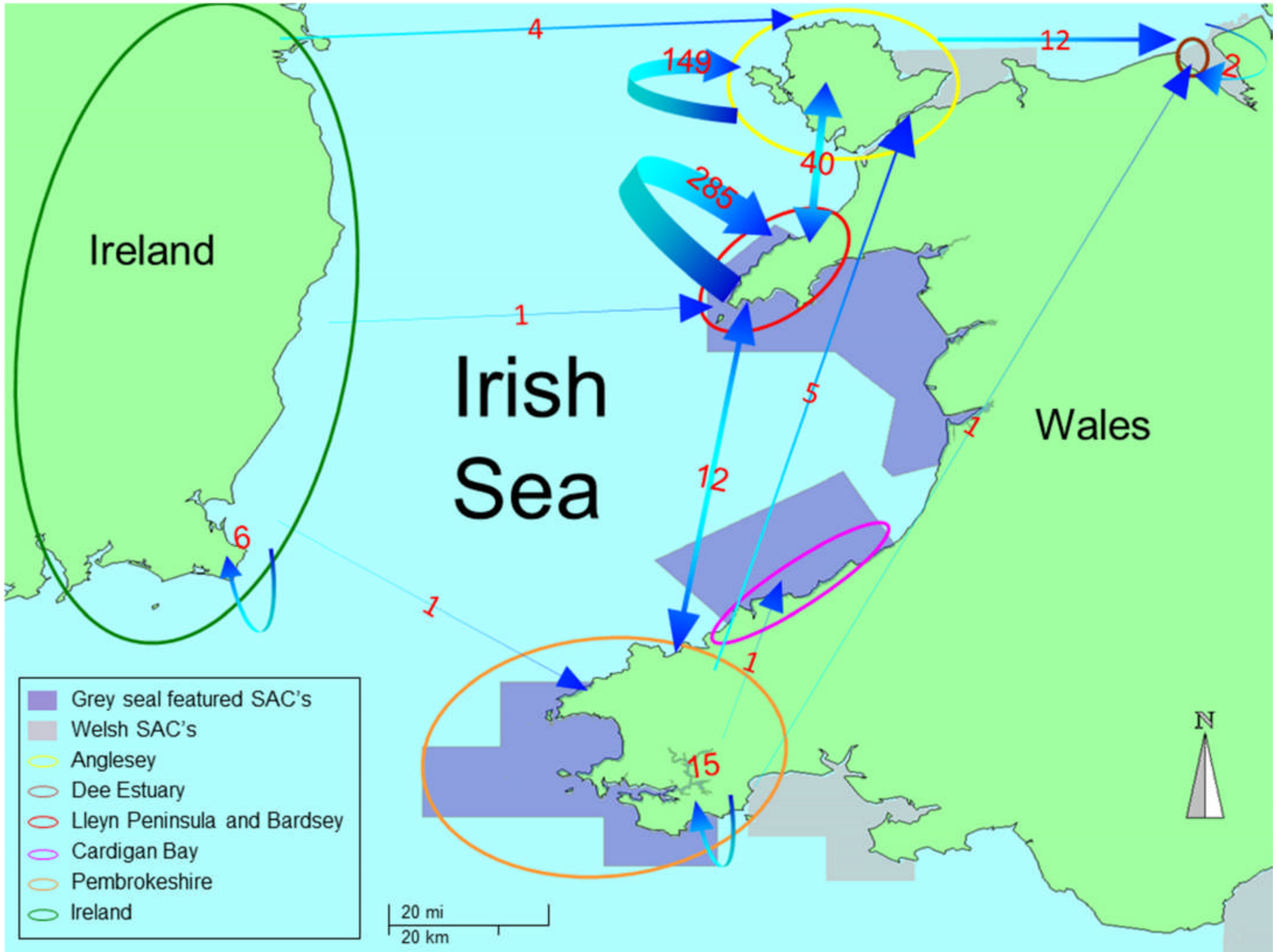

Figure 8. ***Movements of grey seal individuals derived from photo-identification recaptures from 1992 to 2011.*** *Single-headed arrows represent movement from one area to another, whilst double-headed arrows represent movements between the two areas. Recoiling arrows are recaptures of individuals that had not been recaptured out of the original area. Numbers within the arrows show the number of movements .*

Harbour seals

Between 2003 and 2006, 24 ARGOS SRDL telemetry tags were deployed on harbour of ages one year and over. Additionally nine were deployed at Margate Sands, Thames in 2006. Of these, eight were ARGOS SRDL tags and one was a GPS/GSM tag. In January 2012, 25 GPS/GSM tags were deployed on harbour seals in the Wash, of which 22 collected data for more than one week. Additionally ten GPS/GSM tags were deployed in the Thames, split evenly between Margate Sands and Southend on Sea (Figures 9 and 10).

A full quantitative comparison of historic and current activity will be carried out in future and a report will be available for SCOS 2014. However, an initial inspection of the data suggests that the general at-sea activity is similar. Most activity remains within 100 km of the major Wash haulout sites (Figure 9). The interchange between the haulouts in the Wash, Blakeney Point, Donna Nook and the Thames also persists.

In the absence of direct measures of food ingestion we cannot unequivocally identify foraging sites, but on the basis of dive and movement patterns we believe that foraging occurs throughout the movement range. Overall, the intensity of habitat usage is assumed to indicate the level of foraging activity and allows for identification of foraging hotspots. A state-space model of seal activity budgets which will classify dive and movement behaviour into foraging and transiting periods is being developed under funding from DECC and Marine Scotland and a report will be available for SCOS 2014.

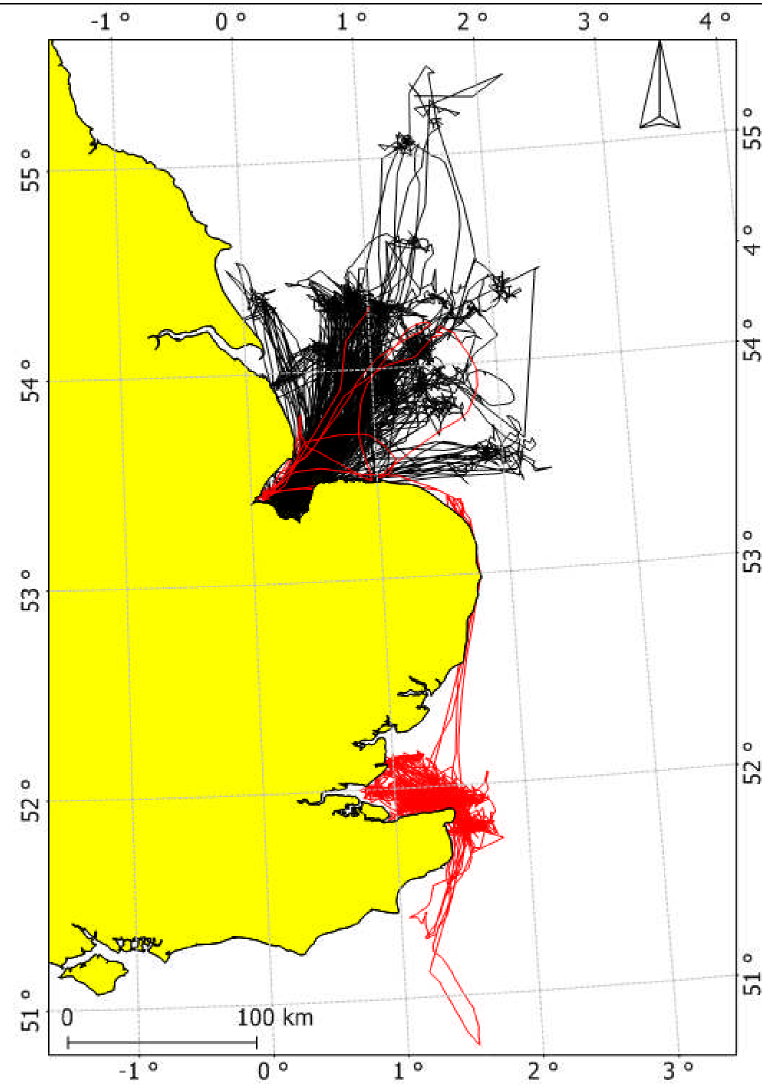

Figure 9. The tracks of harbour seals tagged in the Wash in 2003, 2004 and 2005 are shown in black. The tracks of animals tagged in Margate Sands Thames in 2006 are shown in red.

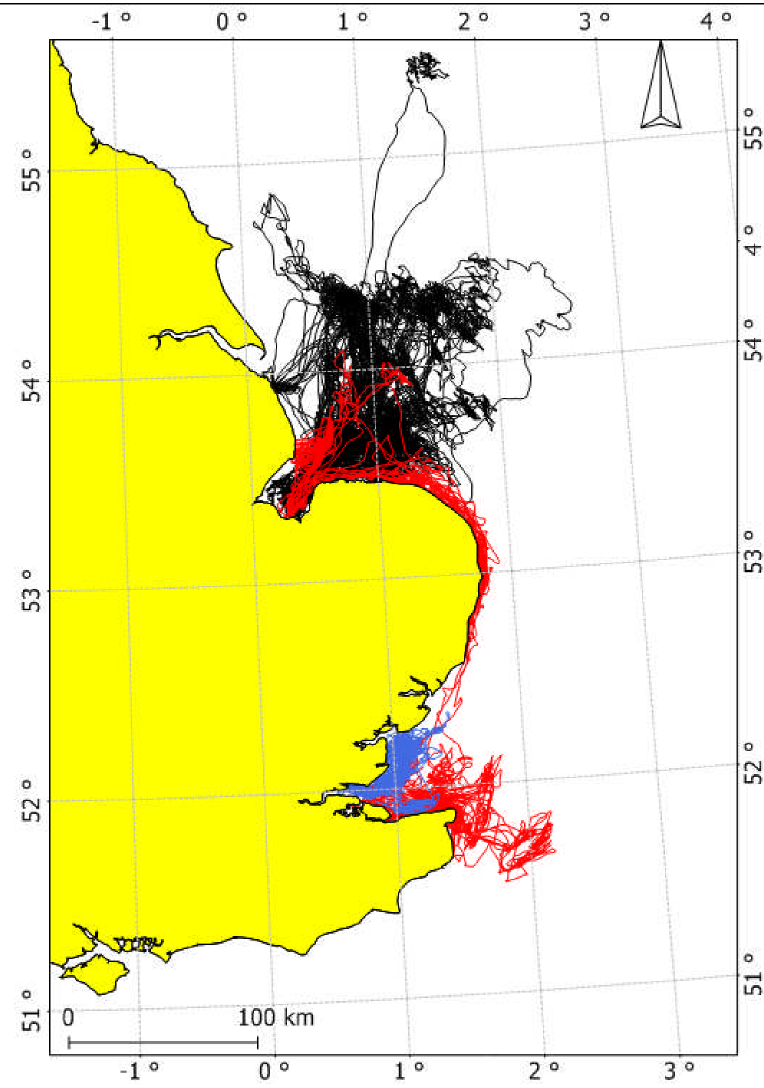

Figure 10. The tracks of harbour seals tagged in the Wash in 2012 are shown in black. The tracks of animals tagged, in 2012, at Margate Sands and Southend are shown in red and blue respectively.

6. Are there any disease outbreaks which are likely to have a significant impact on English seal populations within the next 12 months and if so, what practical mitigation measures might be possible and appropriate?	Defra Q7

No disease outbreaks likely to impact English seal populations have been identified in 2012.

PDV is known to be a recurring disease and there is a possibility of another outbreak in the next few years. Serology results from both species suggest that PDV is not currently circulating in the UK. However, epidemiological models indicate an inter-epidemic period of approximately 13 years. Given that the last outbreak was in 2002, 14 years after the first outbreak, another epidemic might be expected within the next few years. A contingency plan for responding to another outbreak is currently being developed in conjunction with Marine Scotland and the Scottish Marine Animal Strandings Scheme. Mitigation measures such as vaccination have been widely discussed and assessed but logistical as well as epidemiological considerations have concluded that there are no practical mitigation measures to prevent future PDV mortalities.

A recently published collaborative SMRU study[20] described in detail the variability of the Class I Major Histocompatibility Complex (MHC Class I) genes and the differences in these genes between grey and harbour seals. The MHC Class I genes are important for ensuring sufficient diversity to bind foreign agents and particles and defend the host from a wide range of microorganisms. MHC Class I genes are particularly important for defence against viral infection and are highly polymorphic. Of some note was the finding that survivors of the 2002 PDV epidemic were significantly different at MHC Class I compared to the victims, possibly reflecting a difference in relative resistance and susceptibility to PDV. However, the survivors were from the Tay/Eden population and the victims were from the Wash so it is possible the differences are due to population structuring. In addition grey seals have a greater number and more polymorphic MHC Class I genes than harbour seals which could in general contribute to a general resilience of their immune defences against PDV and other viral infections. Further work in this area is needed.

[20] Hammond, J.A., Guethlein, L.A., Norman, P.J. & Parham, P. (2012) Natural selection on marine carnivores elaborated a diverse family of classical MHC class I genes exhibiting haplotypic gene content variation and allelic polymorphism. Immunogenetics, 64, 915-933.

Grey Seal Populations

7. What progress has been made in integrating grey seal population abundance models or selecting between these models using grey seal survey work undertaken in 2009?	Defra Sec Q1

There have been no specific developments in this area and therefore no new information to add.

- Two models of grey seal population dynamics were fitted to the English and Scottish regional estimates of pup production and to the independent estimate of total population size just before the 2008 breeding season.
- One model allowed for density dependence in pup survival, while the other allowed for density dependence in female fecundity.
- Incorporating the independent estimate of population size (counts of grey seals hauled out during the summer) suggest that the model incorporating density dependent pup survival is more appropriate. This 'pup-survival' is the model currently used to estimate the total grey seal population size

8. Which survey techniques would be most appropriate and robust for estimating abundance and distribution of seals in Wales, given that approximately 50% of pups are born in caves which make up 50% of pupping habitat?	NRW Additional census questions

The current methods for estimating the abundance and distribution of seals in Wales, using ground counts, remain the most appropriate.

Populations that do not breed in caves are clearly more readily surveyed on the ground. Surveying pupping sites and counting pups born in caves is clearly a difficult undertaking. Previous methods have involved swimming or kayaking into the caves which is risky and logistically very challenging. Other cave-breeding species, such as Mediterranean monk seals are counted using cameras triggered by movement and powered by solar panels. This could be an option for the Welsh sites, particularly if cameras were set up in the summer when the caves are more accessible, but this would involve investment in equipment and technology not currently used in the UK.

9. What population demographics would be most useful to collect for wider UK population assessments? Conducting a Wales-wide census will inform local-scale conservation reporting requirements, but can you give a reasoned opinion on whether conducting a census in Wales would make a worthwhile contribution to UK scale estimates? Would other research on demographics such as seal movements, population structuring (genetic, stable isotopes etc.) provide better scientific and financial value?	NRW Additional census questions

The most important parameters for robust population estimates remain pup and adult survival and female fecundity rates, which are difficult to obtain for grey seals.

Recent developments in photo ID techniques and initiatives within the Cardigan Bay area and elsewhere in Wales and the southwest will certainly assist in providing some data on adult apparent survival probabilities. However, these may be limited where coverage is only partial. Data on movements, genetic differentiation and population structure would certainly be fundamental for regionally important management and mitigation questions but it is difficult to prioritise when the opportunities or resources available for carrying out such studies are unknown. However, a population census in Wales would certainly make a worthwhile contribution at a UK as well as at a Welsh level.

Harbour Seal Populations

10. Is the decline in harbour seals recorded in several local areas of the UK continuing or not and what is the position in other areas?	MS Q3; Defra Sec Q3;

The status of local harbour seal populations varies around the UK. Details of surveys carried out and the counts obtained are given above in answer to Question 1 and in SCOS-BP 13/03.

The population trends in the different survey/management regions around Scotland are shown in Figure. 11. The latest survey results confirm that:

- The Orkney and North Coast harbour seal population declined by approximately 75% since 2000. Including the 2010 counts, the population has been falling at an average rate of approximately 13% p.a. since 2000 (Figure 11). The 2010 count was similar to the 2008 count, suggesting an end to the rapid decline but additional count data will be required to test this.
- The Shetland harbour seal population declined by approximately 30% since 2000. However, the Shetland survey in 2009 produced an identical count to that in 2006. Again, this suggests that the rapid declines may have ended but additional count data will be required to test this.
- The Western Isles harbour seal population has fluctuated without an obvious trend.
- The counts in the Wider Moray Firth increased by more than 40% between 2009 and 2010, but then decreased by 30% in 2011 and 2012 (Figure 12). This count was still 20% higher than the mean of counts for 2007-2009. This recent fluctuation followed a period of 5 years during which the counts have remained approximately steady. Nevertheless, recent survey data indicate that the population is no longer declining.
- The population in the Firth of Tay has declined dramatically, by approximately 85% since 2000, and has declined at an average rate of 18% p.a. over the last 13 years (Figure 13). Since 2009, the rate of decline seems to have slowed, but the population is at critically low numbers.
- The harbour seal populations of West Scotland may have increased since the late 1990s.
- The English East coast population declined after the 2002 PDV epidemic, but the count increased by 22% in 2012 compared with 2011. The population has now returned to its pre 2002 epidemic levels.
- The nearest European population, in the Wadden Sea, has continued to grow at approximately 12% pa since the 2002 PDV epidemic.

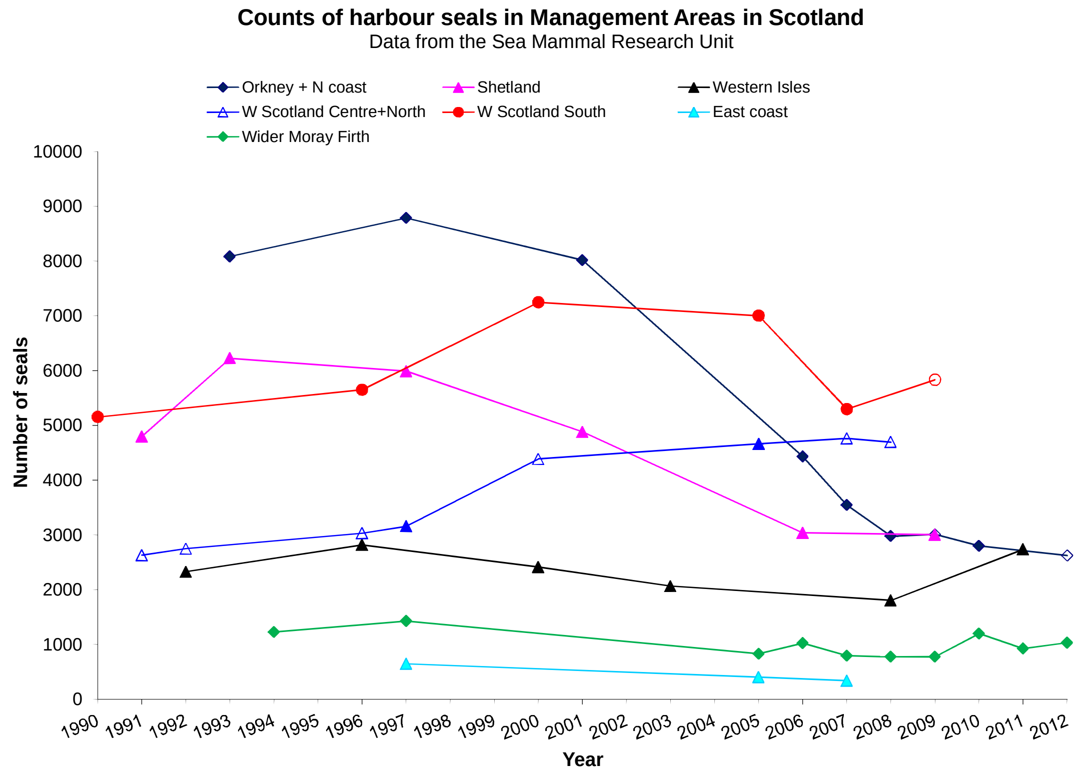

Figure 11. ***Counts of harbour seals in management areas in Scotland***.

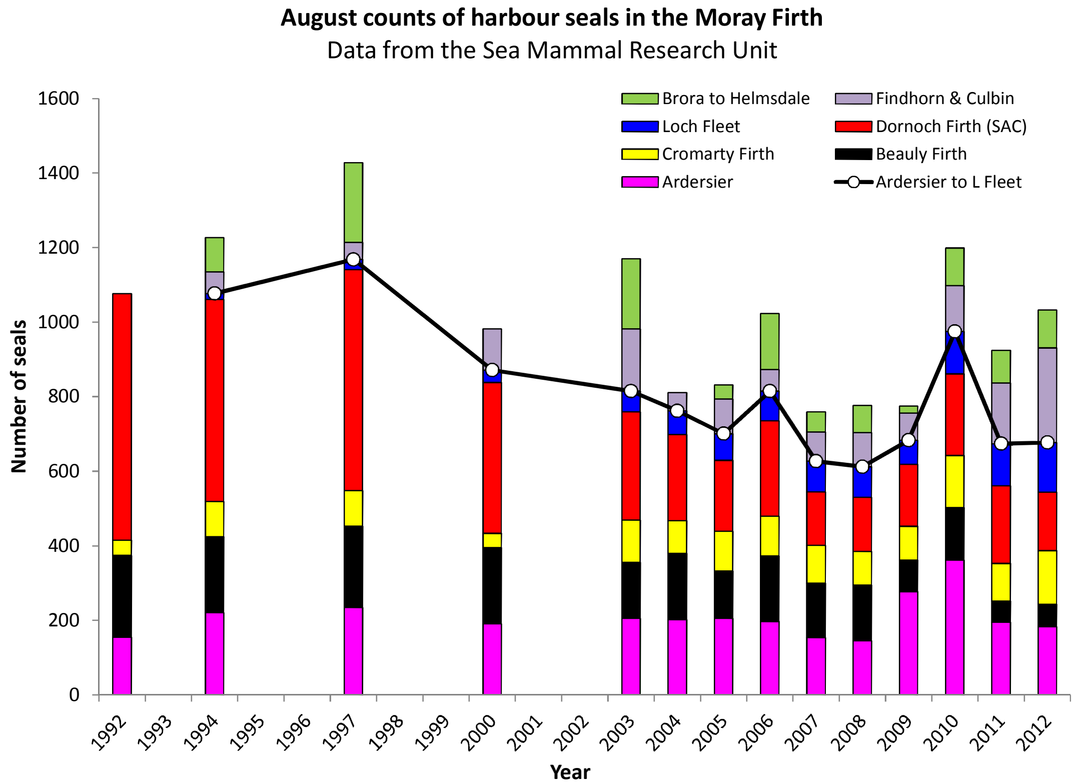

Figure. 12. ***August counts of harbour seals in different areas of the Moray Firth.*** *The black line represents the total count for all areas between Ardersier and Loch Fleet.*

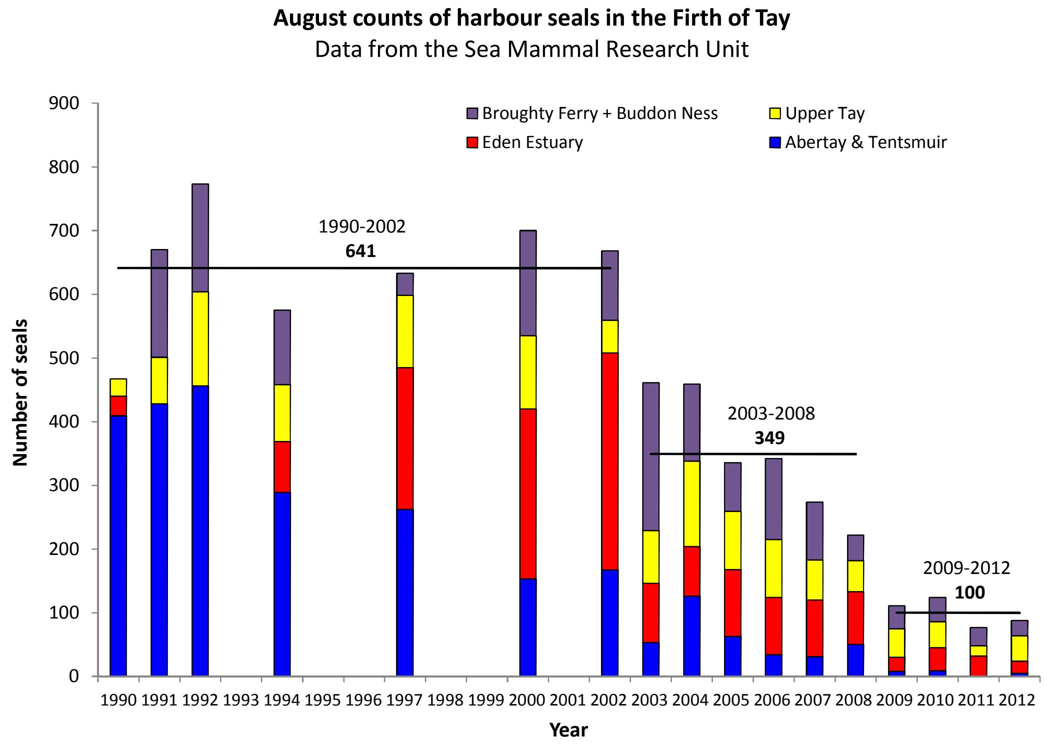

*Figure 13. **August counts of harbour seals in the Firth of Tay.** Horizontal lines are the mean counts for the three time periods.*

11. What is the latest estimate of seal population numbers in the Wash?	Defra Sec Q11

Harbour seals

Two aerial surveys of harbour seals were carried out in Lincolnshire and Norfolk during the annual moult in August 2012 (SCOS-BP 13/03 Tables 2 and 5 and Figure 14 therein). The 2012 counts in the Wash were 3,225 and 3,519.

Results of surveys conducted in the Wash in 2012 are reported in SCOS-BP 13/03 and briefly in answer to Questions 1 and 10.

Overall, the combined count for the English east coast population (Donna Nook to Scroby Sands) in 2012 was 22% higher than the 2011. The English population has now returned to its pre 2002 epidemic levels, but is still lagging behind the rapid growth of the Wadden Sea population that has been increasing consistently since 2002 and increased by 12% p.a. between 2008 and 2012.

A study to establish a monitoring programme to provide regular estimates of pup production of the harbour seal population in the Wash SAC was carried out in 2012 and details are given in SCOS-BP 13/04. A survey conducted around the expected peak date (01/07/2012) produced counts of 1,469 pups in The Wash during the 2012 breeding season compared with 1,106 pups in 2011 and 1,432 pups in 2010. The 2012 pup count was 33% higher than the 2011 count, and similar to the 2010 peak count. Estimated peak pup counts have increased at an average rate of 9% p.a. since 2003 although there is interannual variation.

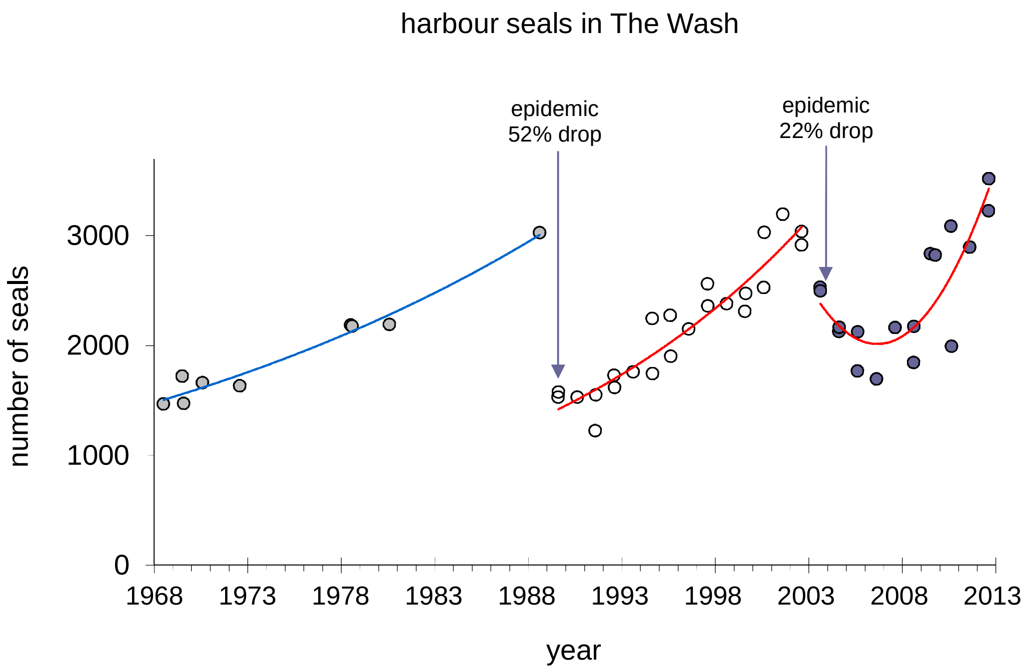

Figure 14. ***Counts of harbour seals in The Wash in August, 1967 - 2012***. *These data are an index of the population size through time.*

Grey seals

As described above, grey seal population estimates are obtained from pups counted during the breeding season. There are no breeding grey seals in the Wash. There are large and rapidly increasing breeding colonies at Donna Nook in Lincolnshire, Blakeney Point in Norfolk and Horsey in Suffolk and pup production trajectories for these colonies were described in SCOS BP 11/01.

In addition to the increasing *breeding* population in the region, there have been rapid increases in the numbers of grey seals counted during the *summer* months (Figure 15). The summer haulout count for the coasts of Lincolnshire, Norfolk and Suffolk between Donna Nook and Scroby Sands have been increasing at an annual rate of 18% p.a. since 1988. In addition, the rate may be increasing; the higher count in 2012 was approximately double the counts in 2009 and 2010.

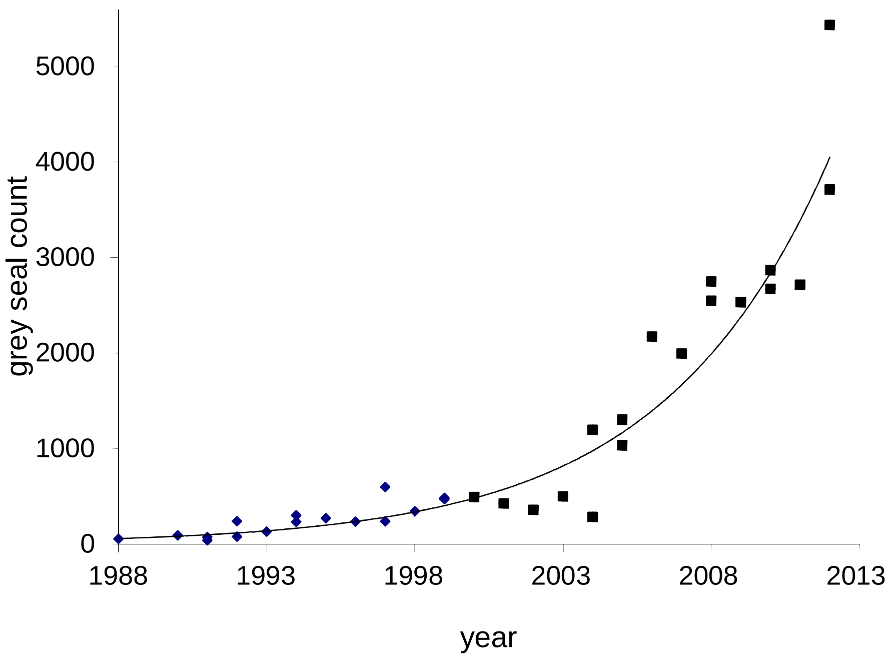

Figure 15. ***Counts of grey seals hauled out in Lincolnshire, Norfolk and Suffolk during August over the period 1988 - 2012***.

12. What are the latest results from research investigating the causes of the failure in the common seal population to recover from pre2002 PDV outbreak numbers and how has this improved understanding of the potential causes?	Defra Sec Q12

The latest survey has confirmed the recovery of the harbour (common) seal population since the 2002 PDV epidemic. There has been a rapid increase in the numbers of seals counted in eastern England over the last three to four years. The most recent counts take the population back to its pre-2002 PDV epidemic level.

13. In light of the latest reports, should the Scottish Government consider additional conservation measures to protect vulnerable local common/harbour seal populations in any additional areas to those already covered by seal conservation areas or should it consider removing existing conservation measure in any areas?	MS Q4

The measures to protect vulnerable harbour (common) seal populations should remain in place.

The dramatic decline in the population of harbour seals in the Firth of Tay and Eden Estuary SAC is a clear cause for continued concern. In addition, no sign of recovery was seen in the sub regions of Orkney that were surveyed in 2012.

Conservation orders are currently in place for the Outer Hebrides, Northern Isles and down the east coast as far as the border. Following the same precautionary principle as earlier (SCOS 2012), a conservation order was extended to the Outer Hebrides. The recent large increase in the Outer Hebrides is unexplained and in light of the uncertainty in the current status of the population SCOS recommends that the conservation order should remain in place.

The recent survey results for a sub-sample of the West Scotland haulout sites showed a 15% increase over the 2007 counts of the same sites/areas. The overall 2007 count for Strathclyde was approximately 30% lower than the peak of 7,900 in 2000. If the sub-sample is representative of the whole area, then the 2009 estimate would be higher than counts in 1988, 1993 and 1996 suggesting that there has been little change over the longer term. As Strathclyde region now holds the largest component of the Scottish harbour seal population, SCOS recommends that a watching brief should be maintained.

SCOS consider that these conservation orders are likely to benefit harbour seal populations, with the situation in the Tay and Eden SAC to still be very serious. Further investigation of the causes of mortality in in the Tay and Eden SAC should continue to be a priority for research.

14. What is the latest understanding of the causes of the recent decline in harbour seals and possible mitigation?	MS Q5; Defra Sec Q4;

Research into the causes of the decline in harbour seals is continuing.

Prior to SCOS 2012 a Scottish Government funded workshop on the causes of the recent declines in harbour seal abundance and possible mitigation measures was held at the University of St Andrews. Reports from this workshop can be found at http://www.smru.st-and.ac.uk/documents/1279.pdf and http://www.smru.st-and.ac.uk/documents/1280.pdf

The major causes under consideration include:

- Nutritional stress – as a result of decreased quality or quantity of prey
- Increased competition with grey seals – although the nature of the competition still to be determined
- Increased competition with other marine animals – as above
- Disease
    - Infectious (i.e. viral, bacterial, fungal, parasitic, protozoal)
    - Non-infectious (e.g. persistent organic pollutants)
    - Toxins (biotoxins from harmful algae, e.g. domoic acid, saxitoxin, okadaic acid, yessotoxins)
- Deliberate killing – shooting is known to have been an issue in the Moray Firth
- Trauma (accidental killing) – increased traumatic interactions with vessels have been demonstrated in certain regions but the true extent of this impact is not known.
- Bycatch – in fisheries
- Pollution – this related back to non-infectious diseases as a potential causal factor
- Predation – certainly an increase in killer whale sightings in Shetland and Orkney especially over the last few years has raised this as a potential problem for harbour seal population abundance, particularly in the summer.

Additional causes that were recognised by the workshop break-out groups were:

- Loss of habitat – either foraging, moulting or breeding
- Anthropogenic disturbance – including increased ocean noise, boat traffic, disturbance from haulout sites
- Direct competition with fisheries – also depleting the prey base

- Dispersal and emigration – the permanent movement of animals into other, European populations or perhaps into the stable populations on the west coast
- Climate change
- Natural variation – unidentified reductions in survival and fecundity
- Entanglement in marine debris

Of all those factors considered the top three explanations to emerge were (a) increased competition with grey seals and other top predators (b) natural variation (c) biotoxin exposure.

The priority research areas identified for **immediate** consideration were:-

- An investigation of the spatial (moult counts and at-sea distribution estimates) overlap between grey seals and harbour seals. There is a clear need to carry out a comparison study. The data are available both at SMRU and from elsewhere. Whatever is happening is **not operating** in the Southern North Sea so these data could potentially be very helpful in directing research priorities and providing information on 'control' or comparative regions where trends and population trajectories are different.
- How do the foraging areas for harbour seals change during the grey seal breeding season (September to December) to when a large proportion of the population of the grey seal population are on land?
- What is the condition of harbour seal pups at weaning and the early survival of pups? A limited study was carried out by SMRU in 2007 at two regions but this has not been repeated.
- The groups emphasised the importance of strandings data – especially samples that could provide information on diet (e.g. stomach contents), causes of death, condition, teeth and whiskers for isotope and blubber for nutritional analyses.
- Key study sites should be identified for which there are diet, harbour and grey seal population data and fish prey data. These sites could then become a key focus for integrated studies investigating the relationship between these species. – **Post-workshop Note:** These regions need to be carefully chosen as it seems quite likely that factors affecting harbour seals may not be consistent among regions.
- A quantitative analysis of direct and indirect effects of shooting should enable this hypothesis to be tested and ruled in or out[21].

Mitigation

Various mitigation options were discussed but detailed issues were not highlighted as the groups felt unable to comment beyond the general statement that

1. If the cause is anthropogenic AND impact on population can be demonstrated then intervention would be acceptable
2. If it was found to be interspecific competition or other natural drivers then intervention would not be recommended
3. A cost-benefit analysis would have to be carried out
4. A major point for action could be to suspend all licences to shoot seals
5. If investigations into the "corkscrew" seal deaths were able to determine the boat type and gear type then intervention may be possible here
6. If fisheries were seen to be involved then again mitigation may be possible
7. Threat of disease - if PDV were to return to Scottish waters then the vaccination issue might be raised again. However, in discussions with the rehabilitation centres and in consultation with other groups faced with the same issue (such as the Hawaiian monk seals) it may only be useful to vaccinate the few seals that are taken into rescue centres. SMRU produced a guide to vaccinating

[21] Matthiopoulos, J., Cordes, L., Mackey, B., Thompson, D., Duck, C., Smout, S., Caillat, M., Thompson, P. (2014). State-space modelling reveals proximate causes of harbour seal population declines. Oecologia. 174(1); 151-162.

wildlife after the first PDV outbreak which suggested that only under a very few, specific circumstances would this be an option on a population-wide basis.

15. In those areas where a decline in common/harbour seal numbers has been recorded in recent years, given a business as usual scenario, what is the projected future population growth/decline?	MS Q6

The population trajectories for areas where there is a reported decline in harbour seals numbers are unknown.

A detailed analysis of the likely trends in the Tay and Eden SAC were presented in SCOS-BP 12/04. This is the area with the most rapid and prolonged decline in Scotland, having experienced an 85% decline since 2000. Simple population models suggest that the continuation of current trends would result in the species effectively disappearing from this area within the next 20 years. And while the cause of the decline is unknown it must be reducing adult survival[29]. However, this analysis is based on the assumption that the population vital rates (survival and fecundity) will not change. The reliance on this assumption means that these trends are associated with a great deal of uncertainty.

16. In those areas where there is continued decline (i.e. Firth of Tay), are there practical actions that might be taken to assist the recovery of these populations? And what are the key questions about seal populations that remain to be addressed to better inform practical seal management issues?	MS Q7; Defra Sec Q5;

Population vital rates (survival and fecundity) are key parameters that remain to be addressed. Reliable estimates of these drivers of population change which would better inform practical seal management issues.

These questions are answered in response to Question 14 above in relation to the causes of the harbour seal decline and the possible mitigation measures. These aspects were carefully considered at the 2012 harbour seal decline workshop by a range of scientists, stakeholders, NGOs and policy makers. Practical action beyond the conservation orders already in place was considered extremely difficult until the cause or causes of the decline were identified.

17. What progress has been made in improving monitoring methods and abundance estimates of the common seal population?	Defra Sec Q2

The methods used to estimate the abundance of harbour seals on a UK-wide scale are the best currently available.

The number of seals hauled out during their annual moult in August, when they spend the largest proportion of their time on land, are photographed and counted. Most regions are surveyed by a method using thermographic aerial photography although conventional photography is used to survey populations in the east coast estuaries. SMRU aims to survey the whole coastline across five consecutive years. However, the majority of the English and Scottish east coast populations are surveyed annually.

The estimated number of seals in a population based on these methods contains uncertainty. A large contribution is the proportion of seals not counted during the survey because they are in the water. This proportion is known to vary in relation to factors such as the time of year, the state of the tide and the weather. Efforts are made to reduce the effect of these factors by standardising the time of year and weather conditions and always conducting surveys within two hours of low tide. In 2012 estimates using flipper mounted satellite transmitters were obtained at locations, Orkney and Arisaig, which estimated the proportion hauled out during the survey window at 72% (95% CI 54%-88%)[22]. Further studies are needed to determine if this proportion is representative of other harbour seal populations.

For some sites, such as the Moray Firth and the Wash, pup counts as well as moult counts are obtained. These data are being used to develop a population dynamics model for harbour seals[35].

There are however, some areas of England not surveyed by SMRU as the surveys currently only cover the area from the Humber estuary to the Kent coast. There are additional small numbers of harbour seals outside this region but it is not currently cost effective to survey these areas. SMRU therefore relies on anecdotal reports of harbour seal numbers and sightings within these regions. Occasionally efforts in conjunction with other organisations (such as tracking the movements of harbour seals in Chichester harbour on the south coast in collaboration with the Hampshire and Isle of Wight Wildlife Trust and Chichester Harbour Conservancy) allow us to more accurately estimate these numbers but not being able to carry out a complete survey of the English and Welsh coastline (including the Isle of Scilly where harbour seals are now starting to be seen) will be a source of additional uncertainty.

18. Is there any evidence that seals move between protected sites and have any passages been identified?	Defra Sec Q6

There is evidence that grey seals move between protected sites and specific routes and restricted corridors are evident in some regions. Harbour seal movements, however, are more local and limited interchange between sites in, for example Orkney has been identified.

Whilst most grey seal foraging trips return to their departure site[23], it is not uncommon for them to relocate to haulouts hundreds of kilometers away. There is evidence of movements between pairs of SAC's (for example Northumberland and Berwickshire coast, Isle of May, North Rona, Monach Isles and Treshnish Isles). Russell et al. (2013) [24] attempted to quantify the links between grey seal foraging areas and breeding colonies. They found that although many seals bred in the same region in which they foraged, between 21% and 58% used a different region, with the degree of fidelity varying among regions.

Harbour seal movement is more local, yet passages have been documented between Orkney and Shetland. Whilst there are few specific individual examples, telemetry data suggest there may be limited interchange between East Sanday, Mousa and Yell SAC's.

19. Is there any evidence of any risks posed to seals between protected areas that they move between?	Defra Sec Q7

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

[23] McConnell, B.J., Fedak, M.A., Lovell, P. & Hammond, P.S. (1999) Movements and foraging areas of grey seals in the North Sea. Journal of Applied Ecology, 36, 573-590.

[24] Russell, D.J.F., McConnell, B., Thompson, D., Duck, C., Morris, C., Harwood, J. & Matthiopoulos, J. (2013) Uncovering the links between foraging and breeding regions in a highly mobile mammal. Journal of Applied Ecology, 50, 499-509.

The large scale movement of grey seals make it likely that seals from every grey seal SAC could, potentially, be at risk. Harbour seal movements are less wide-ranging.

A report to Scottish Natural Heritage entitled *Utilisation of space by grey and harbour seals in the Pentland Firth and Orkney waters*[25] identified potential risks to seal SAC's posed by the introduction of tidal turbines in the area of the Pentland Firth and Orkney. Both species overlap with potential tidal developments.

Among harbour seals, no foraging trips from the Sanday SAC overlapped with potential tidal generating sites. However such 'SAC seals' could also move south to other haulouts sites, and foraging trips from these latter site indicated a risk of overlap. Thus it is important to quantify the transition rates between haulout sites to determine secondary risk to harbour seals SACs Work (funded by SNH and Marine Scotland) is currently underway to do this for the proposed Sound of Islay tidal turbine array. Progress on this will be reported to SCOS in 2014.

Seal Diet

20. What progress has been made with the current seal diet study and what is the timeframe for its completion?	MS Q8

The current seal diet study is nearing completion and results will be available for SCOS 2014.

The new seal diet study has a number of different objectives.

Estimation of harbour seal digestion factors

The final feeding trial from which harbour seal digestion factors will be calculated was completed in November 2012 and associated laboratory work was completed in February 2013. Six harbour seals (1 female and 5 males) were used in the trials; it proved very difficult to catch female seals. Prey fed to the seals in a wide range of replicated feeding trials were: Atlantic salmon (including smolts), cod, dab, dragonet, haddock, hake, herring, lemon sole, lesser sandeel, greater sandeel, Norway pout, plaice, poor cod, red gurnard, squid, whiting, witch. This series of harbour seal feeding experiments has generated data that are similarly comprehensive to those for grey seals in a previous project.

Grey seal diet composition and prey consumption 2010/11

All grey seal scats have been processed and all fish otoliths have been identified. All grading and measuring otoliths and identification and measuring of cephalopod beaks is complete. In total, 3,205 grey seal scats (2,865 Scotland and 357 England) have been processed of which 2,160 scats (1,888 Scotland and 272 England) contained fish otoliths and/or cephalopod beaks. Analysis of grey seal diet data from 2010/11 is currently underway and results, including decadal-scale comparisons with previous grey seal diet estimates in 1985 and 2002, will be available for SCOS 2014.

Harbour seal diet composition and prey consumption 2010/11

Laboratory processing of harbour seal scats from Scotland began in October 2012; 2,616 scats have been washed and fish otoliths and cephalopod beaks have been recovered from 1,973 scats (including those collected from mixed haul-out sites and identified as harbour seal using DNA analysis). 95% of scats have had prey remains identified and approximately one third have been graded and measured. All Scottish harbour seal scats have been processed, and otoliths and beaks identified, graded and measured. Analysis of the data will be conducted during autumn 2013. Results on regional and seasonal variation in harbour seal diet are expected to be reported to Scottish Government early in 2014.

[25] SMRU Ltd (2011) Utilisation of space by grey and harbour seals in the Pentland Firth and Orkney waters. *Scottish Natural Heritage Commissioned Report No. 441*.

21. What is the latest estimate of consumption of commercially important fish by seals in English waters?	Defra Q4; NRW Q5

New estimates of prey consumption by seals in English waters will be available at SCOS 2014.

Until the new data are available, the latest estimates of consumption of commercially important fish by grey seals in English waters remain those from 2002 data published in 2006[26]. The estimates by seasonal quarter for the two major regions in England (Donna Nook and the east coast, largely the Farne Islands although including samples collected from the Isle of May) are shown in Table 7. This represents consumption in these regions by 2,500 grey seals at Donna Nook and 13,300 grey seals on the east coast. Clearly these estimates are outdated and, as outlined above new information will be available next year.

There are no published estimates for the consumption of commercially important fish taken by harbour seals in English waters. Data on the diet of harbour seals in the Wash[27] from the late 1990s found the diet was dominated by whiting (24% by weight), sole (15%), dragonet (13%) and sand goby (11%) with other flatfish such as dab, flounder and plaice making up a further 12%. The current harbour seals diet study will be the first to estimate fish consumption at a population level across all UK regions.

In addition there are no published studies on the diet of grey seals in the West England and Wales Management Unit[28].

[26] Hammond, P.S., Grellier, K., 2006, Grey seal diet composition and prey consumption in the North Sea. Final report to Department for Environment, Food and Rural Affairs on project MF0319. 54pp.
[27] Hall, A.J., Watkins, J., Hammond, P.S., 1998, Seasonal variation in the diet of harbour seals in the south-western North Sea. Marine Ecology Progress Series 170, 269-281.
[28] Brown, SL., Bearhop, S., Harrod, C., McDonald, RA, 2012. A review of spatial and temporal variation in grey and common seal diet in the United Kingdom and Ireland. JMBA, 92(8) 1711-1722

Table 7. ***Estimated consumption of fish prey (tonnes) consumed by grey seals in different regions and seasons in the North Sea in 2002.*** *Listed species contribute >5% in any quarter and species of commercial importance.*

(a) Donna Nook 2002

	Quarter 1		Quarter 2		Quarter 3		Quarter 4	
Species		95% CI		95% CI		95% CI		95% CI
Cod	**36.6**	14.8-73.0	**26.3**	8.6-50.1	**28.6**	8.7-61.9	**93.8**	28.0-206.3
Whiting	**111.1**	47.1-201.1	**37.6**	17.0-65.0	**43.3**	17.3-81.6	**148.1**	57.3-283.4
Haddock	**1.5**	0-5.0	**19.4**	1.9-47.6	**2.4**	0-8.0	**31.8**	2.5-84.0
Sandeel	**85.1**	17.6-222.7	**265.3**	102.0-472.1	**94.4**	29.1-206.0	**164.1**	11.4-405.2
Sole	**53.9**	23.3-98.3	**52.1**	17.1-108.8	**7.2**	0.8-19.4	**26.4**	9.5-56.6
Plaice	**3.2**	0.6-7.3	**29.1**	5.3-69.4	**4.7**	1.4-9.9	**28.9**	8.3-61.0
Herring	**41.1**	7.3-89.4	**2.9**	0.5-8.0	**0.4**	0-1.5	**24.3**	5.4-59.8
Dragonet	**184.1**	95.2-306.8	**204.3**	92.4-389.8	**325.5**	186.7-495.2	**21.6**	9.2-39.5
Short-spined seascorpion	**203.4**	102.7-374.1	**96.8**	38.2-214.1	**277.3**	153.0-460.8	**260.0**	100.8-508.7
Long-spined seascorpion	**76.7**	26.0-237.9	**12.1**	3.5-44.6	**40.7**	12.6-129.3	**21.6**	1.7-120.4

(b) East Coast 2002

	Quarter 1		Quarter 2		Quarter 3		Quarter 4	
Species		95% CI		95% CI		95% CI		95% CI
Cod	**505.1**	153.1-1242.7	**93.4**	20.3-250.7	**102.8**	0-421.9	**389.6**	144.0-846.4
Whiting	**166.1**	55.4-376.7	**182.3**	39.4-482.5	**8.6**	2.3-20.6	**59.9**	15.0-136.5
Haddock	**708.5**	263.7-1558.2	**231.4**	38.9-655.3	**343.3**	42.3-991.7	**613.7**	191.7-1352.7
Saithe	**2.5**	0-26.9					**1.6**	0-21.5
Norway pout	**2.6**	0.4-7.1	**1.8**	0-7.7			**7.7**	1.6-20.0
Sandeel	**2251.3**	1247.7-3314.4	**2543.6**	1518.9-3655.2	**2820.7**	1853.2-4078.4	**2201.4**	1258.4-3303.5
Plaice	**51.8**	13.7-135.8	**233.9**	61.3-607.8	**120.3**	33.4-306.8	**40.6**	9.0-95.5
Herring	**3.6**	0-12.4	**5.3**	0-17.9	**9.8**	0-38.3		
Sprat	**0.7**	0-2.6	**0.7**	0-3.4			**0.3**	0-1.1
Dragonet	**112.2**	40.8-272.8	**269.4**	47.5-764.2	**39.2**	0-152.8	**56.7**	18.0-131.3
Garfish							**6.6**	0-35.9
Short-spined seascorpion	**85.1**	14.0-284.2	**58.2**	0-257.0	**133.0**	0-474.0	**448.0**	185.0-997.0
Long-spined seascorpion	**4.1**	0-30.6						

22. What work might be done to follow up and maintain the detailed picture of grey seal diet obtained from the major survey in 2002, given the infrequent opportunities for such surveys and how useful would this be in informing seal management?	Defra Sec Q8

Results from the grey and harbour seal diet study currently being carried out will be available for SCOS 2014.

23. How is the research into quantifying the consumption of salmon and seal trout smolts and salmon kelts by seals progressing?	Defra Sec Q9

No such studies are underway in England but some work has been carried out in Scotland.

Observations of seals consuming salmonids in Scottish rivers during regular surveys between 2005 and 2008 allowed an estimation of total consumption by month. Numbers of salmonids consumed peaked in winter in all three rivers, thought to be the result of targeted predation on kelts. Additional data on kelt predation were also collected in the river Kyle in winter 2010.

A research program in Shieldaig to directly monitor predation by harbour seals on sea trout smolts using PIT tags and a purpose built seal-borne recorder and transmitter system was carried out in 2010/2011. Three seals were caught and fitted with loggers. One pit tag was fed to each to confirm the correct operation of the system. A total of 140 days of data were received from the 3 seals. No additional pit tags were detected implying that no tagged smolts were consumed by the study animals.

Seals and salmon netting stations

24. What is the current state of knowledge of interactions between seals and salmon netting stations and possible mitigation measures? And what new research might be usefully done in this area?	MS Q9; Defra Sec Q13

Studies suggest that specialist seals are responsible for the majority of seal activity and presumably predation events at netting stations. Acoustic deterrent devices (ADDs) are effective in reducing seal activity and predation. In a recent study during periods when the ADD was switched *on*, significantly fewer seals were observed and significantly more fish were landed per hour than when the ADD was switched *off*.

A series of observations of seal activity and a photo identification project has been carried out at netting stations in both the Moray Firth and the Angus coast south of Montrose. At the Moray Firth site, ten grey seals and four harbour seals were identified on at least one occasion, and two grey seals made up 63% of the visits to the study area when individuals were identified. There was considerable temporal and spatial variation in the activity of seals at salmon bag-nets. Known seals habitually returned to nets in each year of the study. A briefing paper giving more details of the observation and diet study is given in SCOS-BP 13/05.

Sixteen seals were examined between 2005 and 2010 to assess the diet of seals killed at salmon nets. No sea trout were detected in any sample and, interestingly, no salmon were detected from seals that were killed inside salmon nets (n=8). Three out of the sixteen seals examined contained salmonid prey (19%). Whitefish and flatfish were encountered most frequently.

In 2012, a modified salmon net was tested to assess its effectiveness at mitigating seal interactions. Effectiveness was monitored via land-based observations and underwater video. Preliminary results suggest that undamaged catch per unit effort was *ca.* 70% larger when compared to the unmodified net.

Another mitigation method that may provide an alternative to lethal removal of problem animals is the use of Acoustic Deterrent Devices (ADDs). During 2009 and 2010 an ADD was tested at a fixed salmon net in the Moray Firth. During periods when the ADD was switched *on*, significantly fewer seals were observed and significantly more fish were landed per hour than when the ADD was switched *off*. In 2011, a robust and waterproof version of the ADD was supplied to fishers, who themselves took responsibility for its operation, battery charging and data collection on seal sightings and catch damage. During 2011 the ADD was operated continuously, and a significant reduction was found in both seal damage (5 and 7% in 2009 and 2010, down to 0% in 2011) and seal sightings (16 and 64 in 2009 and 2010, down to 5 in 2011). No seals were shot at this fishery during 2011, and no bycatch occurred. Catch per unit effort was up, and number of hauls per day was down, showing that fishers had more confidence in leaving nets for longer and reducing overall costs.

Seals and fish farms

25. What is the current state of knowledge of interactions between seals and fin fish farms and possible mitigation measures?	MS Q10; Defra Sec Q14

Current studies have found that there does not seem to be any relationship between damage levels at different salmon farm locations and the proximity or local density of seals. ADDs are also used to deter seals from these sites but there are concerns about their effect on cetaceans and the need to ensure they operate reliably. Increased or improved application of standard husbandry techniques, notably cage structure and net tensioning, can substantially reduce the incidence of seal damage to farmed salmon.

Damage by seals at fish farms includes damage to fish through the meshes of fish cages and removal of fish by breaching net cages. In the latter case farmed fish may escape to the wild. Salmon escapes have to be notified to the Scottish Government and in recent years seals have been one of the major causes of fish escapes. These conflicts are addressed by the industry in several ways, including the use of acoustic deterrent devices (ADDs) and lethal removal of individual seals frequenting farm sites under licence. There are concerns that the use of at least some ADDs could constitute a significant disturbance to coastal cetacean populations, which are European Protected species.

SMRU are actively involved in the Salmon Aquaculture and Seals Working Group that brings together industry, animal welfare NGOs and Scottish Government to work towards eliminating the need to shoot seals. Several avenues of research have been initiated through this forum. With funding from Scottish Government and working through members of the SASWG, SMRU has analysed industry data and explored factors that may be associated with damage levels. A report was submitted to Scottish Government at the end of 2012.

There does not seem to be any relationship between damage levels at different salmon farm locations and the proximity or local density of seals. Damage levels seem to increase over the first few months of the production cycle, peaking at about month 10. Again, working in collaboration with SASWG members, SMRU has noted that ADDs can sometimes malfunction acoustically, which is not noticeable to site workers by ear: an acoustic testing device has been built and is being tested by industry.

Several camera systems have been tested at farm sites to develop a means of studying seal behaviour around cages. This work will be continued in 2013 with funding from the Scottish Aquaculture Research Forum (SARF). Field tests of a novel seal deterrence system based on an acoustic signal specifically designed to trigger a seal's startle response were completed in 2012 at three farm sites, and a report was submitted to Scottish Government. These trials endorsed the previous conclusion based on more limited work that the device may be effective in deterring seals at salmon farms.

SCOS believe that increased or improved application of standard husbandry techniques, notably cage structure and net tensioning, can substantially reduce the incidence of seal damage to farmed salmon. Anecdotal information suggests that such measures have allowed some fish farmers to significantly reduce the number of successful seal attacks on nets and dramatically reduce fish mortality.

SMRU have recently completed a study of the responses of seals to low voltage localised electric fields in sea water funded by the SARF. Preliminary trials with both grey and harbour seals indicate that they are sensitive to and can be deterred by these low voltage pulsed fields[29]. Initial results suggest that this method may provide an additional seal deterrent capable of preventing seals from touching the netting of marine fish cages.

Occurrences of seals in fresh water in relation to seasonal salmon runs

26. What is the regularity of such an occurrence?	Defra Sec Q15

There have been no specific developments in this area and therefore no new information to add.

- SCOS is not aware of any information on the frequency or timing of these occurrences in English rivers.

27. Where are the common freshwater locations of such occurrences?	Defra Sec Q16

There have been no specific developments in this area and therefore no new information to add

- Seals are regularly seen in freshwater in the English east coast rivers such as the Tyne, Humber, Great Ouse and Thames.

28. What are effective deterrents in such freshwater locations?	Defra Sec Q17

ADDs are effective seal deterrents that can be used in rivers where site characteristics are favourable

The results of trials using ADDs in rivers carried out by SMRU, funded by Scottish Government, showed that they may be used where site characteristics are favourable. The studies tested one type of ADD in three Scottish rivers during winter when seals are known to return regularly. In each case seal sightings upstream were significantly reduced. One study carried out over three consecutive winters consistently reduced seal presence. The conclusion was that ADDs can form an effective barrier to seals in rivers, particularly when powered by consistent mains power[30]. Further

[29] Milne, R. Lines, J, Moss S & Thompson D. (2012) Behavioural responses of seals to pulsed, low-voltage electric fields in sea water (preliminary tests) ISBN: 978-1-907266-51-5 available at http://www.sarf.org.uk/reports/

[30] Graham IM, Harris RN, Matejusova I, Middlemas SJ. (2011) Do rogue' seals exist? Implications for seal conservation in the UK. *Animal Conservation*.14:587-598

details regarding the deployment and maintenance of these devices can be found in the Fact Sheet produced by SMRU at www.smru.st-andrews and click on Fact Sheets.

29. What damage to salmon stocks is there as a result of seals in freshwater?	Defra Sec Q18

SCOS is not aware of any information on the scale of damage to salmon stocks in English rivers.

There is unquantified evidence of seals interacting with salmon in estuaries and the lower reaches of rivers such as the Tees and Tawe and a number of reported instances of seals moving well up into freshwater. The biggest problem for predation on salmonids is probably in estuaries with some form of natural confinement (e.g. narrow and shallow estuary entrance) or man-made obstruction that holds the fish up (e.g. Tees barrage). Here predation by seals may be significant. Predation in coastal fisheries may be associated as much with the presence of the net, for example in the northeast seals do take salmon from the drift and beach nets.

30. What information, if any, do you have on numbers of complaints of seal damage in England?	Defra Sec Q19

There have been no specific developments in this area and therefore no new information to add

- SCOS is not aware of any information on numbers of complaints of seal damage in England.

31. What information, if any, do you have on seals being killed in England to prevent damage to fisheries during the 'open seasons'?	Defra Sec Q20

There have been no specific developments in this area and therefore no new information to add

- SCOS is not aware any information on numbers of seals being killed in England to prevent damage to fisheries during the 'open seasons'.
- No licence is required to kill seals outside the close season or for protection of fishing operations. There are no reporting requirements in the Conservation of Seals Act except for seals killed under licence.

32. What information, if any, do you have on seals being killed under the fisherman's defence, provided by s.9(1)(c) of the Act?	Defra Sec Q21

There have been no specific developments in this area and therefore no new information to add

- SCOS is not aware any information on numbers of seals being killed in England under the 'fisherman's defence'. There are no reporting requirements in England and therefore no reliable records.
- The killing of any seal in Scotland must now be carried out under licence under the Marine (Scotland) Act 2010 and all such events, for whatever purpose, must be reported.
- Summary information from the initial licence returns is available on Marine Scotland's web site at www.scotland.gov.uk/Topics/marine/Licensing/SealLicensing

Seals and marine renewables

33. What is the current state of knowledge of interactions actual or potential, between seals and marine renewable devices and possible mitigation measures?	MS Q11; NRW Q6

Research into the interactions between seals and marine renewable devices is continuing. It is too early to suggest the most effective possible mitigation measures.

Wind

A DECC funded study of the movement patterns of harbour seals in relation to active operational wind farms and pile driving activity was carried out in 2012 in the Wash; 25 harbour seals were tagged with SMRU GPS/GSM tags and movements were tracked during the installation of piled wind turbine foundations. Further, auditory sensitivity measurements for 18 of the tagged seals were made prior to tagging using electrophysiological techniques.

Studies on the effects of windfarm developments in Danish waters indicate that satellite tagged harbour seals showed some avoidance of the wind farm site at Horns Reef during construction phase during pile driving operations[31]. Although position accuracies made comparisons difficult, seals were observed foraging within the site during the operational phase.

A recent SMRU study funded by the Crown Estate to measure seals movements around operational wind farms in Denmark showed that both grey and harbour seals frequently transited from haulout sites through two nearby wind farms [32]. Visually, there is no obvious interruption of travel at the wind farms' boundaries. All three analyses indicated no significant effect of the operational wind farms on seal behaviour. This is in accord with another local study of haulout counts that concluded that the wind farms had no long term effect on the local seal population trends.

Both grey and harbour seals have continued to use the Scroby Sands haulout site (off East Anglia) (SCOS-BP 11/03) despite the construction of a large wind turbine array within a few kilometers of the site. However, another study of the same area reported a significant post-construction decline in harbour seal haul-out counts[33]. The authors tentatively related this to wind farm construction activities; however, it was not possible in the study to exclude the possibility that other factors such as increases in grey seal numbers were responsible for the reduced harbour seal numbers.

Wave

There is currently no information on the direct interactions between wave energy devices and seals.

Tidal

The only direct information on interactions between seals and marine renewables remains that collected in Strangford Narrows in Northern Ireland where a long term study of seal populations and seal foraging movements has been carried out during the development and deployment stage of SeaGen, a large twin rotor tidal turbine.

Telemetry data shows harbour seals used Strangford Narrows throughout periods of turbine operation and SeaGen is not an overt barrier to their movements. Analysis of movements of all of

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[31] Tougaard, J., O. *et al.* (2006). "Harbour seals on Horns Reef before, during and after construction of Horns Rev Offshore Wind Farm." Final report to Vattenfall A/S. Biological Papers from the Fisheries and Maritime Museum No. 5, Esbjerg, Denmark, 2006. Available at www.hornserv.dk.

[32] McConnell, B., Lonergan, M., Dietz, R. (2012). "Interactions between seals and offshore wind farms." The Crown Estate, 41 pages. ISBN: 978-1-906410-34-6.

[33] Skeate ER, Perrow MR Gilroy JJ (2012) Likely effects of construction of Scroby Sands offshore wind farm on a mixed population of harbour *Phoca vitulina* and grey *Halichoerus grypus* seals. *Marine Pollution Bulletin* 64: 872-881.

the tagged seals showed no statistically significant difference between operation and non-operation of SeaGen; however, this was likely to be partly due to high inter-individual variation in transit rates. Further investigation of the effect of operation and non-operation on seals that transited the Narrows frequently showed that seals did transit less during operation. The biological significance of this is unclear and the study provides no information to assess the possible cumulative effects of multiple devices.

Analysis of land-based visual survey data at Strangford Lough has shown that there has been no change in relative abundance of harbour seals in the Narrows associated with turbine operation, though there is evidence for a small scale (few hundred metres) redistribution of harbour seals during operation.

One of the aims of a recent DECC funded project was to measure the underwater proximity and frequency of seals around the SeaGen turbine using active sonar. The results of this suggested that there were 109 sonar targets that were classified by automated software as marine mammals (these were likely to be harbour seals). The detection rate of these was approximately 5.9 per day. The ranges that 'marine mammal' sonar targets were detected suggest that seals do move in close proximity to the tidal turbine both when it was operational (minimum range=9.9m) and non-operational (minimum=8.4m). Further, sonar detections generally decreased during early morning with a minimum at approximately 05:00. In contrast, there was no significant variation in 'marine mammal' detections in relation to tidal speed and turbine operation (ON/OFF).

A series of acoustic playbacks of tidal turbine sounds have recently been carried out as part of the NERC funded "RESPONSE" project. A programme of land based visual observations of harbour seal activity during signal playbacks plus equivalent control signals were made. Furthermore, the behaviour of individual seals was monitored through swimming tracks of high resolution telemetry tagged seals collected in conjunction with the play back trials. Results of this study are due for reporting in 2014.

34. What is the effectiveness of the use of seal scarers for deterring seals in general and in particular for their use in marine construction projects for mitigating against injury or harm to seals by deterring them?	Defra Sec Q22

Research carried out to date suggests acoustic deterrent devices are effective at deterring seals.

As part of the Marine Mammal Scientific Support Research Programme (MMSS/001/11) SMRU are currently conducting a series of behavioural response trials to assess the reactions of harbour seals to signals from a specific (Lofitech) ADD. This device was chosen because it has previously been shown to displace porpoises at significant ranges (>3km). If it is also capable of displacing seals it may provide a potentially useful pre-piling mitigation measure. Preliminary results of tests with Fastloc-GPS equipped seals in western Scotland suggest that harbour seals take avoiding action at ranges of up to 1km and either move directly away from the signal source or move directly to the shore. Results of these trials will be presented to MS in 2013 and will be presented to SCOS 2014.

Given that behavioural responses by animals are likely to be highly context specific and will depend on factors such as age class, motivation of the animal to remain in the area, and prior exposure history, it is perhaps not surprising that reports of the effectiveness of ADDs is mixed. For example, a study of seal behaviour and haul out patterns in the Bay of Fundy [34] which were close to aquaculture facilities with active ADDs found no overt behavioural responses or avoidance. Further, there were no differences in numbers hauled out that could be correlated with ADD state. In contrast, a study of

[34] Jacobs, S. R., and Terhune, J. M. (2002). The effectiveness of acoustic harassment devices in the Bay of Fundy, Canada: seal reactions and a noise exposure model. Aquatic Mammals 28, 147-158.

captive seals found that that ADD-type signals were effective in deterring seals over short ranges[35]. ADDs have also been succesful in the Baltic Sea to reduce gear and catch damage by grey seals at salmon-trap nets (as opposed to fish farm sites)[36] . A recent study that aimed to test the effectiveness of an ADD at deterring seals from a salmon river reported mixed results; the ADD had no significant effect on the absolute abundance of seals in the survey area in the river, but it did reduce seal movement upstream significantly, by ~50%[37].

It should be noted that the use of ADDs in aquaculture is fundamentally different to their use as pre-exposure deterrents at marine construction projects. At fish farms they are used to deter seals from approaching a strongly attractive stimulus in the form of large concentrations of food. At construction sites the ADD signal will be used to move seals away from a potentially damaging sound source. Therefore, following any initial response to the ADD, the target animals will be exposed to what is most likely a powerful and probably unpleasantly loud noise. In such situations the ADD effect will likely be reinforced by the output from the construction activities.

An update of the results of the experimental use of ADDs at both salmon farms and on salmon bag nets is described in answer to Questions 22 and 23 and trials of a novel device targeting seal startle responses is currently undergoing field trials at a fish farm in western Scotland.

The following reports have previously addressed the use of ADDs:

- DETER-01-07 - SMRU Ltd (2007) 'Assessment of the potential for acoustic deterrents to mitigate the impact on marine mammals of underwater noise arising from the construction of offshore wind farms.'
- SEAMAMD-09 'Acoustic mitigation devices (AMDs) to deter marine mammals from pile-driving areas at sea: Audibility and behavioural response of a harbour porpoise and harbour seals.'
- SUBAMD-09 'Measurements of underwater noise generated by Acoustic Mitigation Devices (AMDs).'

As part of a Marine Scotland funded study, SMRU are currently undertaking an updated literature review on the effectiveness of ADDs on marine mammals which aims to produce a synthesis as a single concise assessment of effectiveness. In addition, part of this work field studies testing the effects of acoustic mitigation measures on seals have been carried out recently. Using a real time tracking system in combination with FastLoc-GPS loggers and purpose built UHF telemetry transmitters, a series of playbacks of a Lofitech seal scarer and other relevant control signals was carried out with ten harbour seals tagged in May 2013.

An Offshore Renewables Joint Industry Programme Strategic Joint Industry "Use of Deterrent Devices & Improvements to Standard Mitigation Measures during Piling" has recently invited tenders. This aims to develop ADDs for multiple marine mammal species, through tests in realistic field conditions it aims to provide evidence that devices will provide the required level of risk reduction for the species concerned, and will develop protocol(s) for the use of ADD(s) and agreed with industry, advisors, regulators and NGOs.

35. What additional work might most effectively improve assessment of possible impacts of marine renewables on seal populations at regional and national level?	MS Q12

[35] Kastelein, R. A., van der Heul, S., Terhune, J. M., Verboom, W. C., and Triesscheijn, R. J. V. (2006). Deterring effects of 8–45 kHz tone pulses on harbour seals (*Phoca vitulina*) in a large pool, Marine Environmental Research 62, 356-373.
[36] Fjalling, A., Wahlberg, M., and Westerberg, H. (2006). Acoustic harassment devices reduce seal interaction in the Baltic salmon-trap, net fishery, ICES Journal of Marine Science 63, 1751-1758.
[37] Graham, IM., Harris, RN., Denny, B., Fowden, D. & Pullan, D. (2009). Testing the effectiveness of an acoustic deterrent device for excluding seals from Atlantic salmon rivers in Scotland. ICES Journal of Marine Science, 66 (5), 860-864.

Research that will improve assessment of the possible impact of marine renewables on seal populations is urgently required.

A comprehensive series of research gaps related to seals and marine renewables is provided in the report to Marine Scotland of MR1 and MR2 within the Marine Mammal Scientific Support Research Programme MMSS/001/11 (http://www.scotland.gov.uk/Resource/0043/00434726.pdf).

An approach which would enable the population consequences of disturbance (PCOD) to be assessed is outlined by Lusseau et al (2012)[38]. PCOD is a population model where assumptions are made about the relationships between observed behavioural responses and vital rates of individuals. Such a framework does not avoid the requirement for information on particular demographic parameters or on the types of dose response relationships linking responses to population processes. However, such an approach can be seen as a sensitivity analysis tool to allow the assessment of the potential effects of different environmental disturbances, particularly the impact of marine renewable energy developments.

Research into the detection and consequences of physical interactions between seals and turbine rotors is also required urgently.

36. What evidence exists about how seals behave around tidal turbine devices, including diving behaviour, and about what might be an appropriate avoidance rate to be applied in collision risk modelling?	MS Q13

Research into the behaviour of seals in tidal rapids where tidal turbine devices are likely to be deployed is continuing.

The only direct information on interactions between seals and marine renewables remains that collected in Strangford Narrows in Northern Ireland where a long term study of seal populations and seal foraging movements has been carried out during the development and deployment stage of SeaGen, a large twin rotor tidal turbine. Further details are given in response to Question 33.

Devices and marine mammals must coincide in both space and time in order for collisions to occur. Although there is evidence of that seals move in relatively close proximity to turbines (at scales of metres), there is currently no direct information on the response behaviour by seals during such proximate interactions. However, monitoring at the SeaGen site is continuing, the results of which may go some way towards answering this question.

37. What evidence exists about common/harbour seal range that might help define possible areas of concern for specific marine renewable developments?	MS Q14

The movement data and haulout data from telemetry studies and the at-sea density maps might help define possible areas for concern for specific marine renewable developments.

At-sea density of individuals has been estimated from haulout counts and haulout-specific foraging patterns, Figures 5 and 6[39]. Usage maps at 5km grid granularity using all data up to the end of 2012

[38] Lusseau, D., Christiansen, F., Harwood, J. Mendes, S., Thompson, P., Smith K., Hastie, G.D. (2012) Assessing the risks to marine mammal populations from renewable energy devices, an interim approach. Workshop Report, CCW, JNCC and NERC, 28pp.

[39] Matthiopoulos, J., McConnell, B., Duck, C. & Fedak, M. (2004) Using satellite telemetry and aerial counts to estimate space use by grey seals around the British Isles. Journal of Applied Ecology, 41**,** 476-491.

are available for harbour seals[40]. This was a deliverable under the Marine Scotland MMSS/001/11 Research Project which reported in January 2013. The usage maps present uncertainty in the form of upper and lower 95% confidence surfaces. These maps will be periodically updated as additional telemetry data is collected by SMRU, together with updated information about haulout counts from air surveys. A plot of all the harbour seal movement tracks, which illustrates the overall range for these animals is shown in Figure. 16.

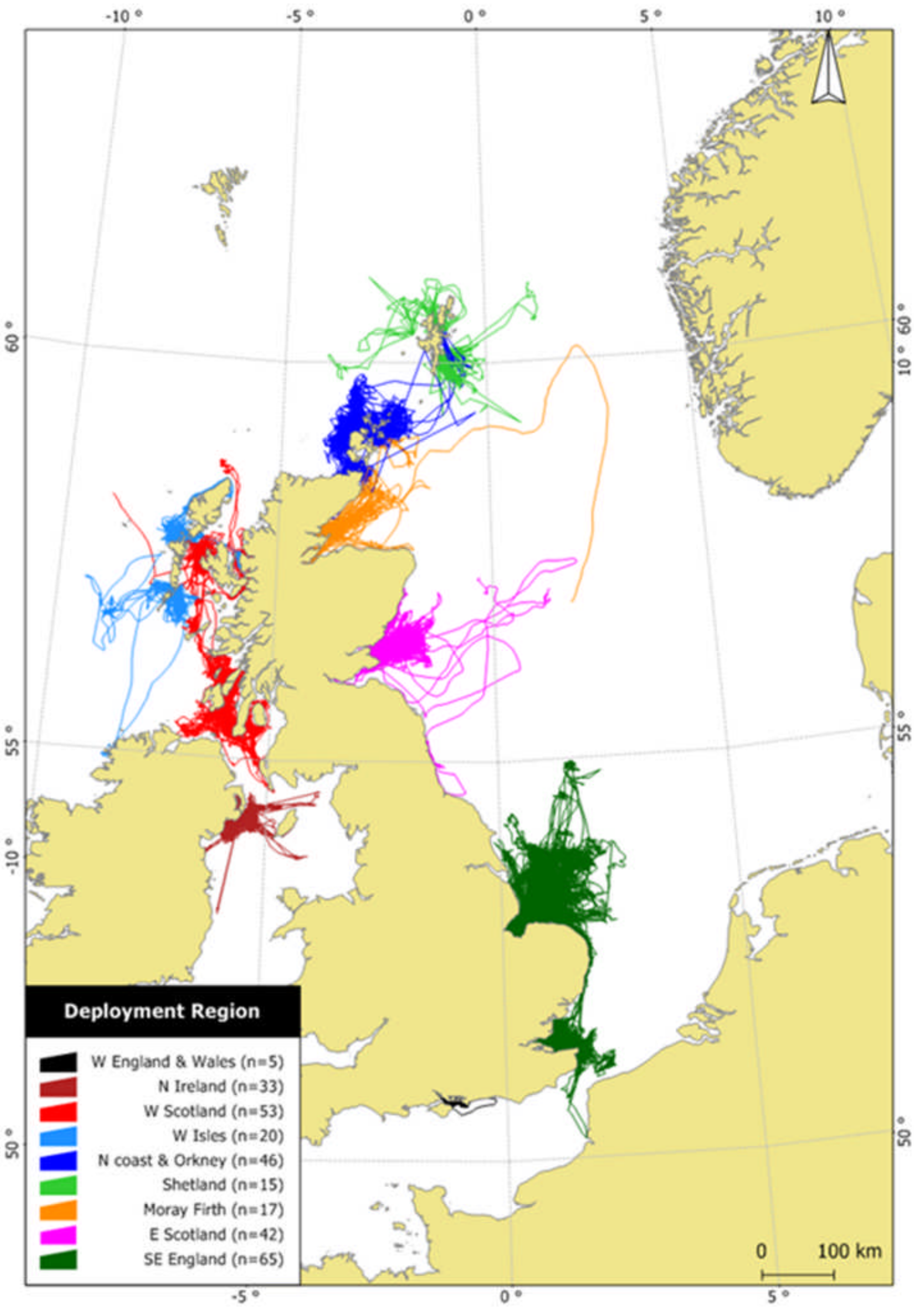

Figure 16. ***Movements of harbour seals by management region from telemetry devices deployed up to 2012.***

[40] Jones, E., McConnell, B., Duck, C., Morris, C.D. & Matthiopoulos, J. (2011) The marine distribution of grey and harbour seals around Scotland. *SCOS Briefing Paper*, pp. 8. Sea Mammal Research Unit, St Andrews.

Whilst at-sea usage maps estimate usage density, they do not provide home ranges estimates of individuals per se. However, a study funded by Marine Scotland and SNH aims to map the network of movements between haul out sites using harbour seal telemetry data. This will generate a transition matrix, illustrating the probability of an animal originating from each haul-out moving to another haul-out or remaining at the haulout of origin. Telemetry data will be used to parameterise these transition matrices. Uncertainty resulting from population size and number of animals tagged will result in confidence intervals surrounding these transition probabilities. This study is due to report in 2013.

Using a combination of funding from NERC, Marine Scotland and SNH, SMRU are conducting a large scale telemetry programme to study the movements of harbour seals in relation to high tidal energy sites. Preliminary results from harbour seals in The Pentland Firth and Kyle Rhea were reported in SCOS-BP 12/10. A NERC funded telemetry study designed to map harbour seal use of tidal areas in high resolution is currently underway in Kyle Rhea. Ten harbour seals were tagged in May 2013 at haulout sites in Kyle Rhea; detailed tracks from all ten seals were collected throughout the summer with close to 100% of all surfacing locations being recorded for all study animals. Results from this study will be available to SCOS 2014.

Seal Licensing and PBRs

38. What, if any, changes are suggested in the Permitted/Potential Biological Removals (PBRs) for use in relation to the seal licence system?	MS Q15

No changes are suggested to the Permitted/Potential Biological Removals method used in relation to the seal licence system.

A project is currently being undertaken for JNCC to apply methods, similar to those used by the IWC for assessing the sustainability of harvests of large cetaceans, to bycatches of marine mammals in European waters[41]. It extends work done to estimate safe limits on bycatches of harbour porpoise[42] to cover other species and incorporate spatial structure. Both grey and harbour seals are included and it will provide a way of using more of the available data in setting limits on the numbers of licenses for shooting seals. However, while it may allow the data to be used more efficiently, this work will still require decisions to be made about acceptable minimum sizes for these populations.

39. What are the best estimates of the levels of seal mortality from anthropogenic sources, other than licensed shooting, in the individual seal management areas around Scotland?	MS Q16; NRW Q7

It is not possible to estimate the levels of mortality from anthropogenic sources. However, some limited information on the numbers of animals examined by the Scottish Marine Animal Stranding Scheme and assigned a cause of death is available.

The only management area for which there are any reliable data on anthropogenic seal mortality before 2011 is the Moray Firth. Data for this area on numbers of seals shot are available as a result of the Moray Firth Seal Management plan. There are no other direct estimates of numbers of seals shot. SCOS are not aware of any reliable estimates of the numbers of seals drowned in nets either deliberately around fish farms or indirectly as bycatch or any reliable estimates of the numbers of seals harmed or killed during any other offshore industrial activities.

[41] Lonergan, M and P. Hammond (2013) Interim report on: Development of bycatch limits for MSFD marine mammal indicators (Contract No: C12-0233-0598). Unpublished report to JNCC.

[42] Winship, AJ (2009). Estimating the impact of bycatch and calculating bycatch limits to achieve conservation objectives as applied to harbour porpoise in the North Sea. Unpublished PhD thesis, University of St Andrews.

However, the Scottish Marine Animal Stranding Scheme (SMASS) now covers both seals and cetacean strandings and a report on the causes of mortality for pinnipeds reported to the scheme between 1992 and 2012 is given in SCOS-BP 13/06. Of the 484 seals (both species) examined at post mortem 50% died of physical trauma. This includes animals shot or those with the emerging, 'corkscrew' or spiral lesions.

In 2012 22 seals were examined by SMASS and details of the findings by region are shown in Table 8.

Table 8. ***Causes of death in seals post-mortemed by SMASS in 2012 by species and region***.

Region	Species	Cause of Death	Number
East Scotland	Grey seal	Physical trauma ("corkscrew")	11
East Scotland	Grey seal	Drowning	1
East Scotland	Harbour seal	Physical trauma ("corkscrew")	4
East Scotland	Harbour seal	Dystocia	1
East Scotland	Harbour seal	Physical trauma – other	1
East Scotland	Harbour seal	Pneumonia	1
East Scotland	Bearded seal	Possible endocrine dysfunction	1
Moray Firth	Grey seal	Entanglement	1
West Scotland	Harbour seal	Verminous pneumonia	1

40. How effective are the current firearm and ammunition minima stipulated in the act in relation to the termination of a seal?	Defra Sec Q23

Results of the tests carried out into the effectiveness of different firearms for killing seals are still to be fully analysed.

Tests using skulls from dead stranded animals were carried out but the findings are not yet available.

Unusual Seal Mortalities

41. What is the latest understanding of the causes of the recent unusual seal mortalities and their potential impact on wider seal populations?	MS Q17; Defra Sec Q23

Research into the causes of the unusual seal mortalities and their potential impact on the wider seal population is continuing.

In 2010 SCOS expressed its concern over the emergence of a new source of anthropogenic mortalities (so called "corkscrew" seals), primarily of pregnant female harbour seals close to the Tay and Eden SAC. SCOS consider that without urgent mitigation the population will continue to decline. SCOS strongly recommended that this cause of mortality be urgently investigated and if identified should be removed or effective mitigation measures be put in place as soon as possible. A preliminary report of the investigation into this mortality event was presented in SCOS-BP 11/07.

Seals with characteristic corkscrew wounds have continued to wash ashore around Scotland with 9 cases in 2013 (4 Harbour seal and 5 Grey seal, Table 9). Since 2010 these events have been mainly concentrated in Scotland. There were no recorded corkscrew seals in England in 2011 or 2012 but three were found close to Blakeney in March 2013.

Table 9. ***Numbers of grey and harbour seal carcasses with characteristic corkscrew wounds recorded in Scotland.***

year	grey seal	harbour seal	Note
1985	-	2	
1998	-	1	
2004	2+*	-	* possibly 5 at Isle of May
2007	1		
2008		2	
2009	1	4	
2010	17*	11	*includes 2 from Northumberland
2011	15	10	
2012	15	6	
2013	4	5	Up to 1/8/2013

Testing the hypothetical link between shipping and unexplained seal deaths

Under a research agreement with a marine propeller developer (VOITH Turbo) SMRU carried out an initial series of tests using different scale models of seals with different materials and a range of sizes. In collaboration with Voith's engineers and fluid dynamics group, a range of model seals using different melting point waxes and flexible RTV silicone to represent the body core and blubber layers were developed. Models were tested in a large flume tank using a 1/10th scale engineering model of a ducted propeller (an Azimuth pod drive system). All trials were videoed and results were photographed. Results were not clear-cut. Unlike the results of preliminary tests, a high proportion of models, especially large models, jammed against the front of the propeller. Those which went through had curving single lacerations similar to the corkscrew wounds.

The propeller used in the Voith model was a new design, with a straight leading edge. Further trials with similar models were carried out in the simplified test rig at SMRU using propellers with both straight and curved leading edges. The result with straight edge blades were similar to the trials at Voith with a large proportion of the models becoming "stuck" on the leading edge. With the curved blade, all models passed through and were lacerated.

A second series of trials have been arranged with VOITH using their original curved blade prop in the same housing. Models have been constructed and the second series of trials are expected to be completed during August/September 2013 although exact timing depends upon the demand for test tank facilities.

Testing the hypothetical reasons for inappropriate responses to propellers.

To date, the most likely explanation of the interactions leading to "corkscrew" wounds is an inappropriate response to some acoustic signal. SMRU in collaboration with SAMS are conducting a series of behavioural response trials with both captive and free ranging seals to assess their responses to propeller noise recordings from vessels with propulsion systems similar to those suspected to be involved. To date the work has been severely hindered by equipment failures, but preliminary trials have been conducted with 4 juvenile grey seals in captivity and are currently underway with wild harbour seals in the Sound of Sleet, Western Scotland. No clear responses have been observed in these initial trials. Additional trials are planned for autumn 2013 with both wild and captive seals.

Use of Automatic Identification System (AIS) to determine potential vessel interactions

The concentration of these carcasses in the Forth and Tay region gives us the best chance of being able to associate "corkscrew" wounds with specific vessel activities. Assessment of vessel movement in and around the Tay and Eden estuaries as well as the Firth of Forth is being monitored using commercial AIS services and the Forth and Tay Navigation Service who have provided access to their historical radar database. This work has not yet produced a direct link between a specific vessel and a seal mortality event. Monitoring will continue.

42. What is the latest position on possible mitigation measures?	MS Q18

To date no effective mitigation measures have been identified although potential changes to shipping operations in the Firth of Tay and Eden Estuary SAC are under discussion.

This situation remains unchanged and dead seals have been reported throughout 2011 and early 2012 (Table 9).

Use of ADDs to exclude seals from specific danger areas during times of particular shipping operations may provide a potential mitigation measure. Results of ADD avoidance studies under MMSS/001/11 (Q33 above) suggest long range avoidance of particular signals. An analysis of those results, including an assessment of their potential as mitigation measures for a range of anthropogenic problems will be presented to MS in 2014 and will be available to SCOS 2014.

Climate change

43. Is there any evidence of significant impacts on seal populations from climate change and are there practical adaptation measures that might be considered to alleviate these?	Defra Sec Q24

At present, there is no evidence for impacts of climate change on harbour or grey seals in UK waters. However, impacts are more likely to be through changes in prey. Thus, no practical measures are likely to be able to alleviate such impacts.

The potential impacts of climate change on marine mammals are not fully understood, but it is anticipated that they will be primarily affected by habitat loss and changes in prey distribution and abundance[43]. Overall, it is thought that the more mobile, adaptable species may be able to respond to these changes by changing their ranging patterns as they search for suitable habitat. However, the extent of this adaptability is unknown. An increase in the spread of diseases to previously naïve populations is also possible, as well as increased disturbance by humans in previously inaccessible

[43] Simmonds, M.P., Isaac, S.J., 2007, The impacts of climate change on marine mammals: early signs of significant problems. Oryx. 41, 19-26.

areas. Further information about the impacts of climate change on the marine system can be found in the Marine Climate Change Impact Partnership Annual Report Cards (http://www.mccip.org.uk/)

Habitat Loss
Warming temperatures, rising sea levels and more severe weather conditions could result in the loss of haul out and pupping sites.

Prey Distribution and Abundance
Changes in environmental conditions as a result of warming temperatures could cause major ecosystem changes affecting the distribution and abundance of marine mammal prey species, including both zooplankton and fish species. For example, major declines in the populations of harbour seals, Steller sea lions and northern fur seals in the North Pacific coincided with the ecological changes observed after the 1976 to 1977 shift in the Pacific Decadal Oscilliation[44]. This shift in ocean currents has occurred historically as a result of changing climate patterns. These shifts lead to substantial changes in the ocean ecosystem that significantly affect the populations of top marine predators by altering the trophic structure of the ecosystem and thus the availability of their major prey species[45]. As a result, there have been both seasonal and area-specific changes in prey concentrations with a reduction in the number of both walleye Pollock and herring for example[46]. As a result, the major decline in Alaskan Stellar sea lions has been attributed to a poorer diet following changes in abundance of their typical prey species such as sandeels and herring. It is hypothesised that they are eating solely gadoid fishes instead of a more balanced and diverse diet containing energy-rich, fattier fishes[47]. While these changes have been mostly attributed to the overfishing of certain prey species and the naturally occurring changes in ocean currents, the potential for ecosystem shifts to have devastating effects on marine mammal populations as a result of climate change is evident.

Heath and Disease
Overall, climate change could have both direct and indirect effects on the health of marine mammal populations. Direct effects include changes in health associated with environmental changes such as loss of habitat, thermal stress, and exposure to severe weather[48]. Indirect effects might include a combination of cumulative impacts on a range of physiological parameters including body condition, immune status, the transmission of pathogens and also exposure to various environmental contaminants[49]. These parameters could be affected by climate change in a number of ways so as to create a knock on-effect leading to the deterioration of the health of the individual. For example, there may be changes in the body condition and nutritional status of marine mammal populations as a result of prey shifts and changes in food webs[50]. The immune function of individuals experiencing nutritional and thus physiological stress will then likely be affected[51]. Indirect effects could also result from changes in host–pathogen associations due to altered pathogen transmission patterns. These occur either as a result of increased pathogen survival and extension range in warming

[44] Hoover-Miller, A., Atkinson, S., Conlon, S., Prewitt, J., Armato, P., 2011, Persistent decline in abundance of harbour seals Phoca vitulina richardsi over three decades in Aialik Bay, an Alaskan tidewater glacial fjord. Marine Ecology Progress Series 242, 259-271.
[45] Frost, K.J., Simpkins, M.A., Lowry, L.F., 2001., Diving behaviour of subadult and adult harbour seals in Prince William Sound, Alaska. Marine Mammal Science. 17, 813-834.
[46] Thomas, G.L., Thorne, R.E., 2003, Acoustical-optical assessment of Pacific herring and their predator assemblage in Prince William Sound, Alaska. Aquatic Living Resources. 16., 247-253.
[47] Rosen, D.A.S., Trites, A.W., 2000, Pollock and the decline of Steller sea lions: testing the junk-food hypothesis. Canadian Journal of Zoology 78, 1243–1250.
[48] Laidre, K.L., Stirling, I., Lowry, L.F., Wiig, Ø., Heide-Jorgensen, M.P., Ferguson, S.H., 2008, Quantifying the sensitivity of Arctic marine mammals to climate-induced habitat change. Ecological Applications. 18, 97–125.
[49] Burek, K.A., Gulland, F.M.D., O'Hara, T.M., 2008, Effects of climate change on Arctic marine mammal health. Ecological Applications 18, S126-S134.
[50] Stirling, I., 2002, Polar bears and seals in the eastern Beaufort Sea and Amundsen Gulf: a synthesis of population trends and ecological relationships over three decades. Arctic (Supplement 1) 1, 59–76.; Stirling, I., Smith, T.G., 2004, Implications of warm temperatures and an unusual rain event for the survival of ringed seals on the coast of southeastern Baffin Island. Arctic 57, 59–67.
[51] O'Hara, T.M., O'Shea, T.J. 2001. CRC handbook of marine mammal medicine. Second Edition. In Toxicology., Dierauf, L.A.D., Gulland, F.M.D., eds. (Boca Raton, Florida., CRC Press), pp. 471–520.

waters, or as a result of transmission between populations of animals as they are forced to migrate in search of food resources and more suitable habitat.

Disturbance

44. What recent research is there on the impacts to seals from visual disturbance (anthropogenic activity) and the recommended distances to maintain away from seals to avoid disturbance?	Defra Sec Q25

Research into the impact of disturbance of seals is continuing.

SMRU are conducting a study investigating the impact of disturbance on grey and harbour seals at haulout sites. A PhD project is underway using a combination of historical telemetry data with simultaneous records of disturbance and vessel traffic, deliberate targeted disturbance of telemetry tagged seals and a series of studies of the energetic costs of disturbance in captive seals. In combination these studies will allow us to determine the behavioural and physiological responses to disturbance and their energetic consequences. Preliminary results from this study will be presented to SCOS in 2014 and the study is scheduled to be completed in 2015.

In the UK there are no seal disturbance regulations limiting approach distances. However, under the Marine Mammal Protection Act (MMPA) in the United States, it is illegal to harass, hunt, capture or kill marine mammals. As such, any actions by persons, vessels or aircrafts that substantially alter marine mammal behaviour may be in violation of the law unless a special permit is in place. The MMPA provides regulations and guidelines about the appropriate human-marine mammal interaction distances in order to both protect the animals, and to increase public awareness of the need to avoid marine mammal harassment. These guidelines are split into vessel, aircraft and individual actions, and also include specific guidelines for seals and sea lions hauled out on land. Specifically, vessels should not approach pinnipeds hauled out on land closer than 100 yards, and swimmers and divers should not approach pinnipeds within 50 yards in the water. Similarly, vessels should not approach pinnipeds within 100 yards while underway, and aircrafts should not circle or hover lower than 1,000 feet above them (http://www.hss.doe.gov/sesa/environment/policy/mmpa.html). Overall, the guidelines emphasize the importance of management strategies that explicitly consider the potential impact of human activities on marine mammal populations. Human disturbance can be in the form of either boat traffic or the presence of people near seal haul-out sites and rookeries. Typical sources of disturbance include motorised vessels, powerboats, non-power boats (canoes and kayaks), pedestrians, and dogs for example. Disturbance is likely to have multiple impacts on seals, but the most visible effects of disturbance can be seen when seals escape into the water from their haul-out sites or when they don't haul out at all[52]. The costs may be two-fold in that disturbance can cause the exclusion of animals from vital haul-out sites for resting or breeding, and there is also an energetic cost to the individual when it escapes into the water.

Generally, seals are most vulnerable to the effects of disturbance during the breeding and moulting seasons. Disturbance during the breeding season can cause pup deaths if they become separated from their mother or experience thermal stress as a result of entering the water before they accumulate enough body fat[53]. Additionally, haul-outs experiencing a high level of disturbance may be abandoned by females completely due to a lack of suitable pupping habitat[54]. For example, there

[52] Mathews, E.A., Pendleton, G.W., 2006, Declines in Harbour seal (Phoca vitulina) numbers in Glacier Bay National Park, Alaska, 1992-2002. Marine Mammal Science 22, 167–189.
[53] Hoover-Miller, A.A., 1994, Harbor seals (*Phoca vitulina*): Biology and Management in Alaska. . Report to the Marine Mammal Commission. Contract Number T75134749.
[54] Allen, S.G., Ainley, D.G., Page, G.W., Ribic, C.A., 1984, The effect of disturbance on harbour seal haul out patterns at Bolinas Lagoon, California. Fishery Bulletin 82.

was higher pup mortality in Hawaiian monk seals on highly disturbed beaches compared to those that were more secluded[55]. Similarly, increased human presence was associated with lower reproductive rates and site abandonment in fur seals in the Gulf of California, Mexico[56]. These lower reproductive rates translated into reduced long-term population growth rates, suggesting that disturbance can lead to declines in this population.

Disturbance during the moult is likely to have the greatest energetic cost. It is thought that seals increase their time spent ashore as an adaptation to avoid additional energy costs associated with the increased blood flow to the skin surface as they replace their coat[57]. Thus, forcing seals to enter the water when moulting can have negative consequences, for example, reduced time spent ashore (in optimal conditions for hair regeneration) may prolong the duration of the moult, and thus increase the time that the animals are unable to forage

Human disturbance has been known to cause problems in harbour seal populations. This is particularly the case because of the tendency for this species to inhabit coastal areas where activities such as vessel traffic, construction, bait collecting and leisure pursuits are common, both on-shore and in the water. In Alaska, a study of cruise ship disturbance to harbour seals breeding on ice floes found that an approach by ships within 500m of a haul-out site increased the risk of seals entering the water[58]. This risk increased to 90% with ice floe approaches under 100m. They also showed that the pups in the glacial Alaska environment are likely to incur an energy deficit if they spent more than 50% of their time in the water. It is likely that they experience low-temperature thermal stress, which, if prolonged, could affect their survival.

[55] Kenyon, K.W., 1972, Man versus the monk seal. Journal of Mammalogy 53, 687-696.
[56] French, S.S., González-Suárez, M., Young, J.K., Durham, S., Gerber, L.R., 2011, Human Disturbance Influences Reproductive Success and Growth Rate in California Sea Lions (Zalophus californianus). PLoS ONE 6.
[57] Paterson, W., Sparling, C.E., Thompson, D., Pomeroy, P.P., Currie, J.I., McCafferty, D.J., 2012, Seals like it hot: Changes in surface temperature of harbour seals (*Phocina vitulina*) from late pregnancy to moult. Journal of Thermal Biology 37, 454-461.
[58] Jansen, J.K., Boveng, P.L., Dahle, S.P., Bengtson, J.L., 2010, Reaction of Harbour Seals to Cruise Ships. . Journal of Wildlife Management 74, 1186–1194

ANNEX I

NERC Special Committee on Seals

Terms of Reference

1. To undertake, on behalf of Council, the provision of scientific advice to the Scottish Government and the Home Office on questions relating to the status of grey and harbour seals in British waters and to their management, as required under the Conservation of Seals Act 1970, Marine Coastal and Access Act 2009 and the Marine (Scotland) Act 2010.

2. To comment on SMRU's core strategic research programme and other commissioned research, and to provide a wider perspective on scientific issues of importance, with respect to the provision of advice under Term of Reference 1.

3. To report to Council through the NERC Chief Executive.

Current membership

Professor D. Bowen (Chair),	Bedford Institute of Oceanography, Canada;
Dr A. Hall	SMRU, University of St Andrews;
Dr S. Wanless	CEH, Edinburgh;
Dr J. Forcada	British Antarctic Survey;
Dr S. Middlemas	Marine Scotland, Science, Pitlochry;
Dr A. Bjørge	Institute of Marine Research, Bergen, Norway;
Dr G. Englehardt	Cefas, Lowestoft;
Professor P. Thompson	University of Aberdeen;
Dr S. Piertney	University of Aberdeen;
Dr V. Norton (Secretary)	NERC, Swindon Office.

ANNEX II

Questions from Marine Scotland

Dear Miss Norton

MARINE (SCOTLAND) ACT 2010 (CONSEQUENTIAL PROVISIONS) ORDER 2010: ANNUAL REVIEW OF MANAGEMENT ADVICE

Thank you for your e-mail of 16 May concerning the next meeting of the Special Committee on Seals on 30 August 2012 and asking whether the Scottish Government has any specific questions on which it would welcome the Committee's scientific advice.

It would be very helpful if the Committee could provide a general update on seal populations and respond to some more specific questions on particular issues as set out below.

We have, as usual, structured our request for advice from the Committee in two broad categories. The first comprises a shorter than usual list of standard questions seeking a update on some of the key information regularly provided by the Committee in previous years:-

1. What are the latest estimates of the number of seals in Scottish waters?

2. What is the latest information about the population structure, including survival and age structure, of grey and common/harbour seals in European and Scottish waters? Is there any new evidence of populations or sub-populations specific to local areas?

Specific questions about improving seal management:-

Common/Harbour Seal Population

3. Is the existing common/harbour seal decline recorded in several local areas around Scotland continuing or not and what is the position in other areas?

4. In light of the latest reports, should the Scottish Government consider additional conservation measures to protect vulnerable local common/harbour seal populations in any additional areas to those already covered by seal conservation areas or should it consider removing existing conservation measures in any areas?

5. What is the latest understanding of the causes of the recent decline in common/harbour seals and possible mitigation?

6. In those areas where a decline in common/harbour seal numbers has been recorded in recent years, given a business as usual scenario, what is the projected future population growth/decline?

7. In those areas where there is continued decline (i.e. Firth of Tay), are there practical actions that might be taken to assist the recovery of these populations?

Seal Diet

8. What progress has been made with the current seal diet study and what is the time frame for its completion?

Seals and Salmon Netting Stations

9. What is the current state of knowledge of interactions between seals and salmon netting stations and possible mitigation measures?

Seals and Fish Farms

10. What is the current state of knowledge of interactions between seals and fin fish farms and possible mitigation measures?

Seals and Marine Renewables

11. What is the current state of knowledge of interactions actual or potential between seals and marine renewable devices and possible mitigation measures?

12. What additional work might most effectively improve assessment of possible impacts of

marine renewables on seal populations at regional and national level.

13. What evidence exists about how seals behave around tidal turbine devices, including diving behaviour, and about what might be an appropriate avoidance rate to be applied in collision risk modelling?

14. What evidence exists about common/harbour seal range that might help to define possible areas of concern for specific marine renewable developments?

Seal Licensing and PBRs

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

16. What are the best estimates of the levels of seal mortality from anthropogenic sources other than licensed shooting in the individual seal management areas around Scotland?

Unusual Seal Mortalities

17. What is the latest understanding of the causes of the recent unusual seal mortalities and of their potential impact on wider seal populations?

18. What is the latest position on possible mitigation measures?

As in previous years, it is our intention to publish a link to the advice provided by the Committee on the Scottish Government web-site. We will liaise about the timing of that in due course.

I also enclose the information requested on licences issued by the Scottish Government during 2012 under The Marine (Scotland) Act 2010. You will be aware that this Act has now replaced The Conservation of Seals Act (1970) in Scotland. This means that information on seal licences issued in Scotland will be presented in a different format from now onwards, one that is considered more appropriate for the new seal licensing system. This information can be found on the Scottish Government web-site through the following link (see Tables 1, 2a and 2b):-

http://www.scotland.gov.uk/Topics/marine/Licensing/SealLicensing/2011/2012

Questions from Defra

Dear Miss Norton

CONSERVATION OF SEALS ACT 1970: ANNUAL REVIEW OF MANAGEMENT ADVICE

Thank you for your email letter of 26 April 2013, asking if Defra has any specific questions on which it wishes to receive scientific advice.

The following are standard questions which were asked in 2012 (these are based on questions previously asked by Scotland in relation to seals in Scottish waters) seeking a general update on information regularly provided by the Committee in previous years. It is understood that each devolved administration would ask similar questions so that a UK wide picture would be provided in the annual SCOS report.

A minor comment: The SCOS advice that is produced every year is quite repetitive in terms of its structure i.e. there are a number of repeated/similar questions from DEFRA and Scottish Government where the response to DEFRA question is just 'See response to Scottish Government'. Is it necessary to have these in there? It would make the advice more succinct and readable if similar questions from the agencies were just combined by NERC. For example, there are two separate sections on marine renewables – 'marine renewables' and 'seals and marine renewables' in the most recent 2012 advice – with questions that are the same.

1. What are the latest estimates of the number of seals in English waters?

2. What is known about the population structure, including survival and age structure, of grey and common seals in European and English waters?

3. Is there any evidence of populations or sub-populations specific to local areas within English waters?

4. What is the latest estimate of consumption of commercially important fish by seals in English waters?

5. Have there been any recent developments, in relation to non-lethal methods of population control, which mean that they could now effectively be applied to English seal populations where appropriate?

6. What are the latest results from satellite tagging in respect of usage of specific coastal and marine areas around England by grey and common seals and whether or not these suggest potential foraging sites?

7. Are there any disease outbreaks which are likely to have a significant impact on English seal populations within the next 12 months and, if so, what practical mitigation measures might be possible and appropriate?

The second category of questions comprises more specific questions and relates to improving seal management. Again, all but the last of these were asked last year, so anything to <u>add</u> to the advice given by SCOS in 2012 would be appreciated:-

Seal populations

1. What progress has been made in integrating grey seal population abundance models or selecting between these models using grey seal survey work undertaken in 2009?

2. What progress has been made in improving monitoring methods and abundance estimates of the common seal population?

3. Is the decline in common seal numbers in specific local areas continuing or not and what is the position in other areas?.

4. What are the latest results from research investigating the causes of the recent decline in common seals and how has this improved understanding of potential causes?

5. What are the key questions about seal populations that remain to be addressed to better inform practical seal management issues?

The transient links between seal populations

6. Any evidence that seals move between protected sites and have any passages been identified

7. Is there any evidence of any risks posed to seals between protected areas that they move between

Seal diet

8. What work might be done to follow up and maintain the detailed picture of grey seal diet obtained from the major survey in 2002, given the infrequent opportunities for such surveys, and how useful would this be in informing seal management?

9. How is the research into quantifying the consumption of salmon and sea trout smolts and salmon kelts by seals progressing?

Seal legislation

10. Does the Committee consider that there is a significant scientific requirement to change the current close seasons for each native seal species?

The Wash

11. What is the latest estimate of seal population numbers in the Wash?

12. What are the latest results from research investigating the causes of the failure in the common seal population to recover from pre 2002 PDV outbreak numbers and how has this improved understanding of potential causes?

Seals and salmon netting stations

13. What research is currently available on interactions between seals and salmon netting stations and what new research might usefully be done in this area?

Seals and fish farms

14. What research is currently available on interactions between seals and fin fish farms and what new research might usefully be done in this area?

Occurrences of seals in fresh water in relation to seasonal salmon runs

15. What is the regularity of such an occurrence?

16. Where are the common freshwater locations of such occurrences?

17. What are effective deterrents in such freshwater locations?

18. What damage to salmon stocks is there as a result of seals in fresh water?

Management –

19. What information, if any, do you have on numbers of complaints of seal damage in England?

20. What information, if any, do you have on seals being killed in England to prevent damage to fisheries during the 'open seasons'?

The same information for Scotland and Wales would also be of interest if not available for England or for comparison with figures from England. MSA seal licence returns from Scotland were be available for SCOS 2012.

21. What information, if any, do you have on seals being killed under the 'fisherman's defence' provided by s.9(1)(c) of the 1970 Act?

22. What is the effectiveness of the use of seal scarers for deterring seals in general, and in particular for their use in marine construction projects for mitigating against injury or harm to seals by deterring them?

We would be especially interested in receiving the results of research into deterrents

Shooting

23. How effective are the current firearm and ammunition minima stipulated in the act in relation to the termination of a seal?

Climate change

24. Is there any evidence of significant impacts on seal populations from climate change and are there practical adaptation measures that might be considered to alleviate these?

Disturbance

25. What recent research is there on the impacts to seals from visual disturbance (anthropogenic activity) and the recommended distances to maintain away from seals to avoid disturbance?

Unusual seal mortalities

26. What is the latest understanding of the causes of the recent unusual seal mortalities and of their potential impact on wider seal populations?

I hope this satisfies your requirements. If you have any queries about this letter please contact me.

Yours sincerely

Questions from Natural Resources, Wales

Dear Vicki

CONSERVATION OF SEALS ACT (1970): ANNUAL REVIEW OF MANAGEMENT ADVICE

Thank you for your email of 30 May 2013 to ask if Natural Resources Wales (NRW) has any specific questions on which it wishes to receive scientific advice.

It would be very helpful if the Committee could provide an update on seal populations and anthropogenic interactions in the West England and Wales management unit (MU). To aid this update, some specific questions have been outlined below. Additionally, advice on a potential Wales grey seal census is sought.

Population structuring and abundance

1. What are the latest estimates of the number of seals in Welsh waters and the West England and Wales management unit (MU)?

2. What is the latest information about population structure, including survival, age, and fecundity, of grey seals in European and Welsh waters? Are there likely to be any substantial regional differences in demographics? In other words, is there any evidence of subpopulations/population structure in Welsh waters compared to the rest of UK?
3. Is there any evidence of population structuring through genetic differentiation or stable isotope profiles between seals in Welsh waters, the West England and Wales management unit (MU), and the rest of NE European waters?
4. What is the latest information on seal movements (satellite tracking or photoID) between colonies in Wales, the West England and Wales management unit (MU), other regions in the UK, Ireland and France?

Diet

5. What is the current knowledge of grey seal diet around the UK and does it differ regionally, with particular emphasis on SW Britain?

Marine renewables

6. What is the current knowledge of interactions between seals and marine renewable devices, especially likely effects of underwater noise and the current thought on suitable mitigation measures? Are there any specific examples for the West England and Wales management unit (MU) area?

Anthropogenic mortality

7. What are the best estimates of the level of seal mortality from anthropogenic sources e.g. bycatch in Welsh waters and the West England and Wales management unit (MU)?

Unusual seal mortalities

8. What is the latest understanding of the causes of 'corkscrew' injuries and likely impacts of these injuries at the population level, with particular emphasis on occurrences of strandings that indicate these injuries in the West England and Wales management unit (MU)?
9. What is the latest position on possible mitigation measures?

Census

NRW are contemplating a repeat of the 1992-95 Wales-wide census of grey seals (Baines et al 1995) to provide a more contemporary estimate of abundance and distribution. The census would mostly consider pup production but haul-out counts at other times of the year might be considered if deemed useful. Advice would be welcomed on several aspects of census design, so that data from such a census are compatible with other UK surveys, are of maximum use for the UK-wide modelling estimates, and would be helpful to the Committee for their future grey seal abundance estimates. Specifically:

Which survey techniques would be most appropriate and robust for estimating abundance and distribution of seals in Wales, given that approx. 50% of pups are born in caves, which make up approx. 50% of pupping habitat?

What population demographics would be most useful to collect for wider UK population assessments?

Conducting a Wales-wide census will inform local-scale conservation reporting requirements, but can you give a reasoned opinion on whether conducting a census in Wales would make a worthwhile contribution to UK-scale estimates? Would other research on demographics such as seal movements, population structuring (genetics, stable isotope) etc., provide better scientific and financial value?

Many thanks for your consideration, it is very much appreciated.

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 current *Briefing papers* should represent a record of work that can be carried forward to future meetings of SCOS.

List of briefing papers appended to the SCOS Advice, 2013

13/01 Grey seal pup production in Britain in 2012: First use of a digital system
Duck, C.D. and Morris, C.D.

13/02 Estimating the size of the UK grey seal population between 1984 and 2012, using established and draft revised priors
Thomas, L.

13/03 The status of British harbour seal populations in 2012
Duck, C.D., Morris, C.D. and Thompson, D.

13/04 Trends in harbour seal (*Phoca vitullina*) pup counts in The Wash
Thompson, D., Connor, L. and Lonergan, M.

13/05 Marine mammals and salmon bag-nets
Harris, R.N. and Northridge, S.P.

13/06 Pinniped strandings in Scotland 1992-2012
Brownlow, A.C., Davison, N. and Foster, G.

Grey seal pup production in Britain in 2012:

First use of a digital system

Callan D. Duck and Chris D. Morris

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

Abstract

In the 2012 grey seal breeding season, SMRU developed and used a new, digital photographic system to survey the main grey seal breeding colonies in Scotland. A NERC equipment grant enabled transfer from the Linhof AeroTechica film camera, used since 1985, to a twin Hasselblad H4D digital system. The cameras were mounted in the existing, but modified, Image Motion Compensating cradle which reduces ground movement as the camera shutters fire. This results in sharper images, particularly in low light conditions.

The resulting digital images were of significantly improved resolution (approximately 2.5 cm/pixel) compared with the film used previously, resulting in (hopefully) more accurate categorization and counts of pups. Considerable processing of the images was required prior to counting, including: brightness and sharpness adjustment, perspective correction and stitching individual frames to create a single high resolution image of each breeding colony.

Because of differences in ground cover per single frame between the large-format Linhof camera and the medium format Hasselblad cameras, the digital system produced approximately 20,000 images from a complete survey of approximately 60 breeding colonies, compared with approximately 6,000 frames produced by the Linhof system.

By July 2013, all images from colonies in the Inner Hebrides, the Firth of Forth and from one survey of Ceann Iar, in the Monach Isles in the Outer Hebrides, have been counted. Images for the remaining colonies, in the Outer Hebrides, Orkney and in mainland Scotland still require processing.

Grey seal pup production in 2012 at colonies in the Firth of Forth was 5,175, compared with 4,279 in 2010, an average annual increase of 10.0%. Pup production at the Farne Islands in 2012 was 1,603, compared with 1,499 in 2010, an annual increase of 3.4%. At colonies in south-east England, pup production in 2012 was 3,359 compared with 2,566 in 2010, an annual increase of 14.4%. All of the above increases were in line with the average annual increase for each area between 2005 and 2010. Pup production at 12 colonies in the Inner Hebrides in 2012 was 4,027 compared with 3,391 in 2010, an average annual increase of 9.0% (although one new colony producing 90 pups was included in 2012). This was very different to the average annual change estimated for the 2005-2010 period which was close to 0.0%. This was the first time that pup production in the Inner Hebrides exceeded 4,000. The initial results for 2012 show that North Sea grey seal colonies are still growing rapidly and indicate that, following several years of very little change, populations off the West coast of Scotland may be increasing again.

Introduction

Grey seals breed at tradition colonies, with females frequently returning to the same colony to breed in successive years (Pomeroy et al. 2001). Some females even return to breed at the colony at which they were born. Habitual use by grey seals of specific breeding colonies, combined with knowledge of the location of those colonies, provides opportunity for the numbers of pups born at the colonies to be monitored.

While grey seals breed all around the UK coast, most (approximately 85%) breed at colonies in Scotland (Figure 1). Other main breeding colonies are along the east coast of England, in south-west England and in Wales. Most colonies in Scotland and east England are on remote coasts or remote off-lying islands. In contrast, many breeding colonies in south-west England and in Wales are either at the foot of steep cliffs or in caves and are therefore extremely difficult to monitor.

Until 2010, SMRU conducted annual aerial surveys of the major grey seal breeding colonies in Scotland to determine the number of pups born. The number of pups born at colonies along the east coast of England is monitored annually by counting on the ground by different organisations: National Trust staff count pups born at the Farne Islands (Northumberland) and at Blakeney Point (Norfolk); staff from the Lincolnshire Wildlife

Trust count pups born at Donna Nook and staff from Natural England count pups born at Horsey/Winterton, on the east Norfolk coast. Scottish Natural Heritage (SNH) staff ground count grey seal pups born in Shetland and on South Ronaldsay in Orkney.

Limitations in funding, combined with increasing aerial survey costs, have resulted in SMRU adopting a biennial survey regime. The first year with no survey was 2011. In 2012, a new digital camera system, funded by NERC, was used, replacing the film-based large-format Linhof AeroTechnika system that has been in use since 1985. The same 60 colonies were surveyed either four or five times, at approximately 10 to 12 day intervals, through the breeding season. Increased numbers of images acquired during a full survey (20,000 digital images compared with 6,000 frames) and a complex image processing procedure prior to counting, resulted in a delay in completing estimating pup production at all 60 colonies. To date, images from all surveys of colonies in the Inner Hebrides and the Firth of Forth have been completed, and from one survey of Ceann Iar, in the Monach Isles in the Outer Hebrides.

This Briefing Paper documents the image processing procedure and reports the pup production estimates for all colonies in the Inner Hebrides and in the North Sea, including a comparing pup production at these colonies in previous years.

Materials and Methods

SMRU aerially surveys the main breeding colonies around Scotland. Pups born at colonies in England are counted from the ground annually by staff from the National Trust (Farne Islands and Blakeney Point), Lincolnshire Wildlife Trust (Donna Nook) and Natural England (Horsey/Winterton).

The numbers of pups born (pup production) at the regularly surveyed colonies in Scotland is estimated from a series of 3 or 5 counts derived from aerial images using a model of the birth process and the development of pups. The method used to obtain pup production estimates in 2012 was similar to that used in previous years. A lognormal distribution was fitted to colonies surveyed four or more times and a normal distribution to colonies surveyed three times.

Between four and five surveys of the main grey seal breeding colonies in Scotland were carried out between September and November 2012. Paired digital images were obtained from two Hasselblad H4D 40MP cameras mounted at opposing angles of 12 degrees from vertical in SMRU's modified Image Motion Compensating cradle (Figure 2). As previously, a series of transects were flown over each breeding colony, ensuring that all areas used by pups were photographed (Figures 3 and 4). Images were recorded directly onto hard drives, one for each camera. Hard drives were downloaded and backed up after each day's survey.

All images were first adjusted for brightness and sharpness using Hasselblad's image processing software Phocus. Individual images were then stretched from rectangular to trapezoid to closely match the ground area covered by oblique photographs taken at an angle of 12 degrees (Figure 3). All perspective-corrected images covering one survey of a particular colony were then stitched together to create a single digital image of the entire colony up to 15GB in size. Images were stitched and exported as PSB files using Microsoft's Image Composite Editor v1.4.4. In a few cases where the stitching software could not stitch all images, such as with images of areas with large differences in ground elevation, images were stitched or adjusted manually using Adobe Photoshop CS5. The final composites were then saved as LZW compressed TIFF files (large images were split if TIFF's 4GB maximum file size was exceeded) and imported into Manifold GIS 8.0 for counting. The imported images were compressed within Manifold to reduce file size without losing too much image detail. Separate layers were created for marking whitecoat, moulted and dead pups (Figures 5 and 6). As part of the process of learning how to manipulate and counts pups on the digital images, adult seals were also counted. These data may prove useful for other studies and are not reported here.

Previously, because there was a significant risk of misclassifying moulted pups as whitecoats, the pup production model used a fixed value of 50% for the proportion of correctly classified moulted pups. Pups spend a lot of time lying on their back or side and, depending on light conditions during the survey, it was possible to misclassify a moulted pup exposing its white belly as a whitecoat. Misclassification, of a whitecoat as a moulted pup was considerably less likely.

The pup production model allows different misclassification proportions to be used. In Shetland, where pups are counted from the tops of cliffs and misclassification of moulted pups is likely to be low, a correctly classified proportion of 90% was used (SCOS-BP 05/01).

The digital images are of sufficient quality to reduce misclassification, so a proportion of 90% was used as the standard run. In case this proportion was incorrect, the proportion was allowed to run free, enabling the model to select a value that provided the closest fit to the raw counts.

Results

The locations of the main grey seal breeding colonies in the UK are shown in Figure 1.

Pup production at North Sea colonies in 2012

New pup production estimates were available for all grey seal breeding colonies in the North Sea (Table 1). Pup production at colonies in the Firth of Forth was 5,175 in 2012 and 4,279 in 2010, an average annual increase of 10.0% (these estimates include 30 pups from Craigleith from 2009). At the Farne Islands 1,603 pups were born in 2012 and 1,499 in 2010, an average annual increase of 3.4%. At colonies between The Humber Estuary and Great Yarmouth, 3,359 pups were born in 2012 compared with 2,566 in 2010, an average annual increase of 14.4%. The pup production increases at these three groups of colonies in the North Sea are similar to the 5-year trend between 2005 and 2010 (Table 1).

Pup production trajectories for all North Sea colonies, including total production, is shown in Figure 7. The 95% confidence intervals are included where available.

Pup production at colonies in the Inner Hebrides in 2012

There was a marked increase in pup production at colonies in the Inner Hebrides by an annual average of 9.0% in 2012 compared with 2010 (Table 1; Figure 8). Prior to 2012, total pup production in the Inner Hebrides increased very slightly between 1992 and 2010, although at a number of colonies production was steadily increasing (Gunna, Nave Island, Oronsay), at others it was steadily decreasing (Lunga, Fladda, Northern Treshnish, Soa) while at the remainder it was fairly constant (Eilean an Eoin, E. nan Ron, Oronsay Strand, Sgeir a'Chaisteil + Eirionnaich). For most, but not all, colonies there was a marked increase in 2012 (Figure 9).

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Pup production at North Sea colonies in 2012

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Pup production trajectories for all North Sea colonies, including total production, is shown in Figure 7. The 95% confidence intervals are included where available.

Pup production at colonies in the Inner Hebrides in 2012

There was a marked increase in pup production, of 9.0%, at colonies in the Inner Hebrides in 2012 compared with 2010 (Table 1). This is the first increase of any significance, without some form of decline in the previous year, since 1991 (Figure 8). Prior to 2012, total pup production in the Inner Hebrides increased very slightly between 1992 and 2010, although at a number of colonies production was steadily increasing (Gunna, Nave Island, Oronsay), at others it was steadily decreasing (Lunga, Fladda, Northern Treshnish, Soa) while at the remainder it was fairly constant (Eilean an Eoin, E. nan Ron, Oronsay Strand, Sgeir a'Chaisteil + Eirionnaich). For most, but not all, colonies there was a marked increase in 2012 (Figure 9).

Discussion

It was not immediately clear whether or not increases in pup production were a consequence of the improved digital photographic system or whether they were a result of changes in the proportion of correctly classified whitecoated pups. It was reassuring that the increases at the Firth of Forth colonies surveyed aerially by SMRU were no different to increases at the remaining North Sea colonies in England which are surveyed by very different methods – by counting pups from the ground. Furthermore, the average annual increases were consistent with the average increase over the previous 5-year interval (Table 1).

The relative totals of whitecoat, moulted and dead pups counted in four surveys in the Firth of Forth colonies in 2010 and 2012 are compared in Figure 10a and in four surveys in the Inner Hebrides in 2010 and 2012 in Figure 10b. The 2012 digital images should enable more accurate assessment of the stage of each pup and a more accurate total count, through better resolution, the ability to magnify the image more easily and the use of a GIS for counting, which enables the classification of every pup to be recorded. The main improvement is likely to be increased ability to identify moulted pups that are lying in dark or rocky areas.

The pup production estimation model was run three times using different proportions of correctly classified moulted pups. The first run used a fixed value of 50% that was standard in previous years. The second run used an increased, but fixed, value of 90%. The final run allowed the model to select the value that would provide the closest fit to the observed counts. The total production estimates using the different values for the Firth of Forth colonies are at the foot of Table 2 and shown, with 95% confidence intervals, in Figure 11. Similarly, the different production estimates for the Inner Hebrides using different classification values are in Table 3 and shown, with 95% confidence intervals in Figure 12. As with the Firth of Forth colonies, the 50% fixed classification gave the lowest production estimate with the widest confidence intervals. The free classification gave a production estimate that was very slightly lower than the 90% fixed classification.

Given the increased resolution of the digital images, we decided to use the most flexible option, allowing the model to select the optimal value for each colony. The values selected by the model for each colony in the Firth of Forth are listed in Table 2 and for each colony in the Inner Hebrides in Table 3.

Without running parallel surveys using the two imaging systems a direct comparison of the two survey systems is difficult. Given that surveys are now biennial rather than annual, due to reductions in SMRU core funding, it was not financially possible to conduct a simultaneous test of the two systems.

There are many advantages of the new digital system. The one disadvantage is the increase in the time required for processing images before they can be loaded into a GIS for counting. As it now takes longer than previously to process some colonies but less time to process others, time will tell whether the new system requires more or less time overall than the old system. Ultimately, however, the digital system will allow individual seals (pups and adults) to be geo-referenced within each colony, thus creating new opportunities for additional data analyses.

Conclusions

The new digital camera system produced images with considerably improved resolution. Counts for all colonies in the Firth of Forth and the Inner Hebrides were completed; counts for the Outer Hebrides, Orkney and north mainland Scotland are not complete. A significantly increased amount of image processing is required prior to loading images into a GIS for counting.

Grey seal pup production in 2012 at colonies in the North Sea (Firth of Forth and east England) showed increases that continued the 5-year trend observed between 2005 and 2010.

Grey seal pup production at colonies in the Inner Hebrides showed an average annual increase of 9% since 2010. This is a significant change following several years of very little or no increase.

References

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

Duck, C.D. and Mackey, B.L. 2005. Grey seal pup production in Britain in 2004. SCOS Briefing Paper 05/01. pp 22-33 in: Scientific advice on matters related to the scientific management of seal populations: 2005. Unpublished Report to the Special Committee on Seals: 2005. Url: http://www.smru.st-andrews.ac.uk/documents/SCOS_05_v2f.pdf.

Table 1. Grey seal pup production estimates from 2012 compared with estimates from 2010. Note that 2012 estimates for colonies in the Outer Hebrides and in Orkney have not yet available.

Location	Pup production in **2012**	Average annual change from 2010 to **2012**	Pup production in **2010**	Change in pup production from 2009 to **2010**	Average annual change in pup production from 2005 to **2010**
Inner Hebrides	4,027	+9.0%	3,391	-0.1%	-0.0%
Outer Hebrides			12,857	+6.1%	+1.0%
Orkney			20,312	+6.1%	+2.4%
Firth of Forth	5,175	+10.0%	4,279	+5.0%	+9.0%
All other Scottish colonies (incl. Shetland & mainland)			3,299 [1]	+4.9%	
Total (Scotland)			**44,138**	**+5.4%**	**+1.9%**
Donna Nook +East Anglia	3,359	+14.4%	2,566	+14.3%	+15.0%
Farne Islands	1,603	+3.4%	1,499	+11.4%	+5.9%
SW England (last surveyed 1994)			250		
Wales [2]			1,650		
Total (England & Wales)			**5,965**	**+8.7%**	**+6.7%**
Northern Ireland			100		
Total (UK)			**50,203**	**+5.8%**	**+2.4%**

[1] Estimate derived from, data collected in different years
[2] Estimate from indicator sites in 2004-05, multiplier derived from 1994 synoptic surveys

Table 2. Grey seal pup production at the main grey seal breeding colonies in the North Sea between 2006 and 2012 (see Figure 7). For the first time, pup production at Fast Castle exceeded production at the Isle of May. Included are production estimates using different proportions of correctly classified moulted pups, and the proportion selected for each colony by the pup production model.

Year	Isle of May	Fast Castle	Inchkeith	Farne Islands	Donna Nook	Blakeney Point	Horsey Winterton	North Sea Total
2006	1,827	804	130	1,254	1,070	234	133	5,452
2007	1,751	1,005	178	1,164	1,194	278	168	5,738
2008	1,875	1,265	206	1,318	1,318	433	202	6,617
2009	2,065	1,715	267	1,346	1,371	579	294	7,637
2010	2,153	1,844	252	1,499	1,417	747	402	8,314
2011				1,555	1,438	932	500	
2012	2,315	2,433	397	1,603	1,525	1,222	612	10,107

Pup productions using different proportions of correctly classified moulted pups; Firth of Forth only

	Isle of May	Fast Castle	Inchkeith	**Firth of Forth Total**
50% fixed	2,175	2,251	348	**4,774**
90% fixed	2,315	2,433	399	**5,147**
free	2,315	2,433	397	**5,145**
Classification proportion	**90**	**90**	**87**	**(mean: 81)**

Table 3. Grey seal pup production at colonies in the Inner Hebrides between 2006 and 2012 (see Figure 9). Included are production estimates using different proportions of correctly classified moulted pups, and the proportion selected for each colony by the pup production model. There was no survey in 2009 due to camera failure and production in 2008 was used as a proxy.

Year	Gunna	N. Tresh	Fladda	Cha+Eir	Lunga	Soa	E. Ron	Oron	E. Eoin	Nave	Oron Stran	Coll Soa	Inner Hebs Total
2006	673	173	328	170	399	63	565	179	432	479	9		**3,470**
2007	671	126	316	106	304	52	508	179	331	478	47		**3,118**
2008	701	158	300	173	325	67	579	194	354	505	40		**3,396**
[2009	701	158	300	173	325	67	579	194	354	505	40		**3,396]**
2010	713	134	275	134	323	62	562	210	411	505	62		**3,391**
2011													
2012	826	130	321	158	422	61	634	259	416	654	56	90	**4,027**
Pup productions using different proportions of correctly classified moulted pups													
50% fixed	792	126	309	133	395	60	570	257	397	577	53	78	**3,747**
90% fixed	829	130	326	158	426	62	634	260	419	654	58	90	**4,046**
free	826	130	321	158	422	61	634	259	416	654	56	90	**4,027**
Classification proportion	**85**	**80**	**72**	**90**	**81**	**65**	**90**	**80**	**78**	**90**	**67**	**90**	**(mean: 81)**

Figure 1. The main grey seal breeding colonies in the UK. Small numbers of grey seals will breed at locations other than those indicated here.

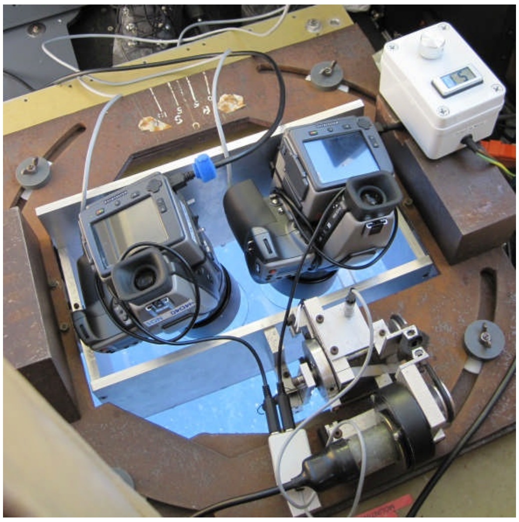


Figure 2. Two Hasselblad H4D-40 medium format cameras fitted in SMRU's Image Motion Compensation (IMC) mount. Each camera is set at an angle of 12 degrees to increase strip width. The cradle holding the cameras rocks backwards and forwards during photo runs. Rocking speed is set depending on the altitude and the ground speed of the aircraft. The camera shutters are automatically triggered and an image captured every time the cameras pass through the vertical position on each front-to-back pass. Images are saved directly to a computer as 60MB Hasselblad raw files and can be instantly viewed and checked using a small LED screen. The H4D-40 can take up to 40 frames per minute allowing for ground speeds of up to 140kts at 1100ft (providing 20% overlap between consecutive frames). The resulting ground sampling distance is approximately 2.5 cm/pix.

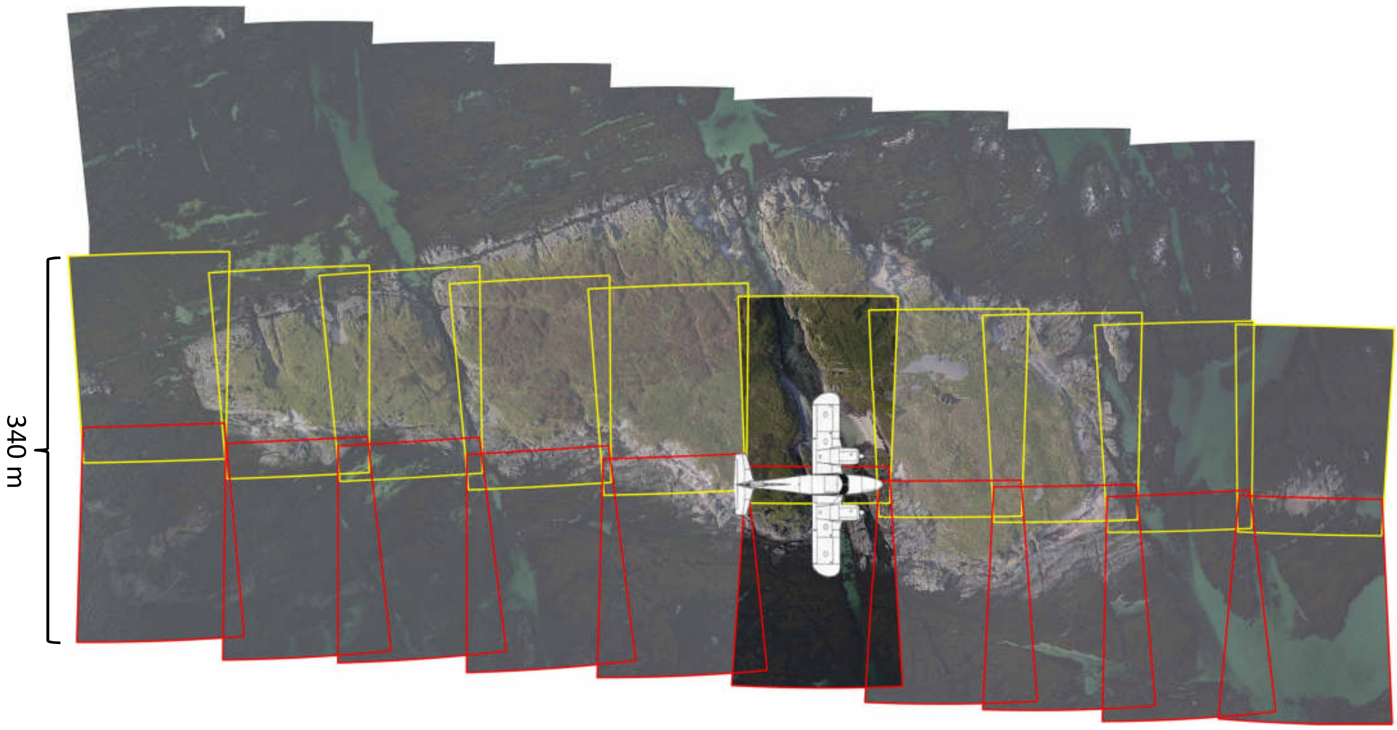


Figure 3. The individual footprints of each pair of photographs taken on a run over Eilean nan Ron, off Oronsay in the Inner Hebrides, flying at 1100 ft (red: left-hand camera; yellow: right-hand camera).

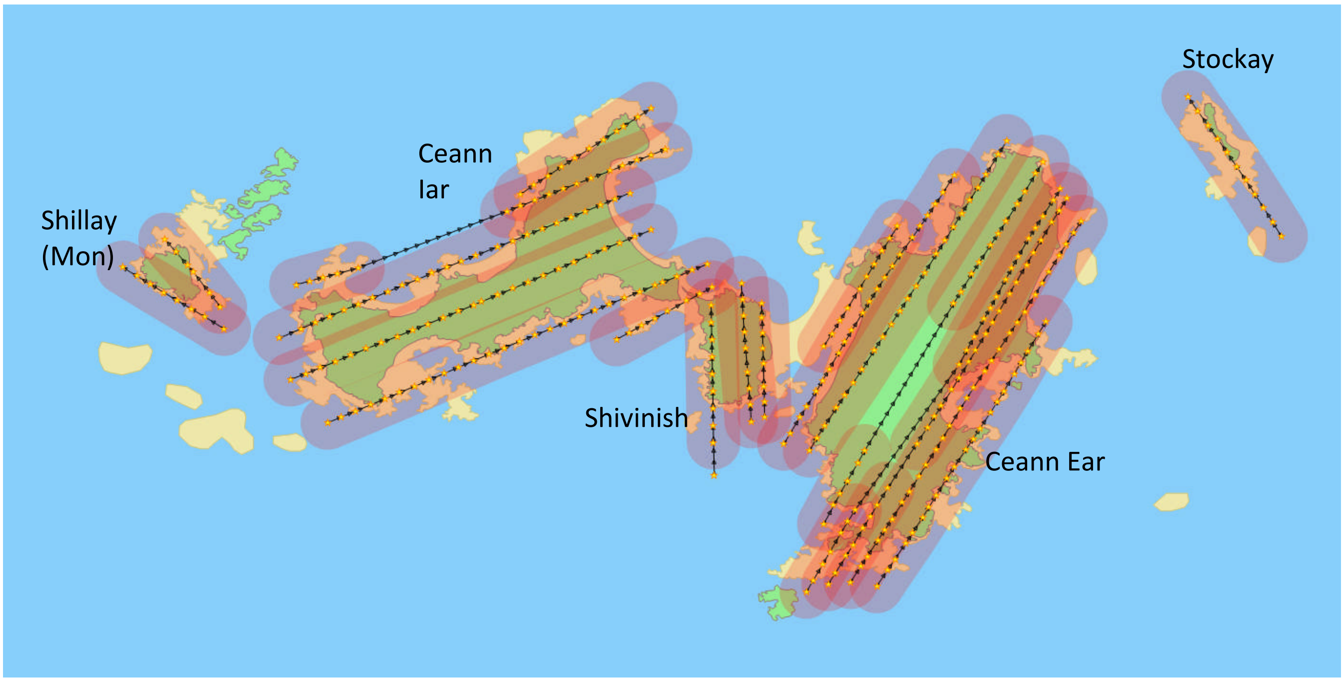


Figure 4. Survey runs and approximate camera trigger locations (yellow dots) for five colonies in the Monach Isles in the Outer Hebrides on 26 October 2012.

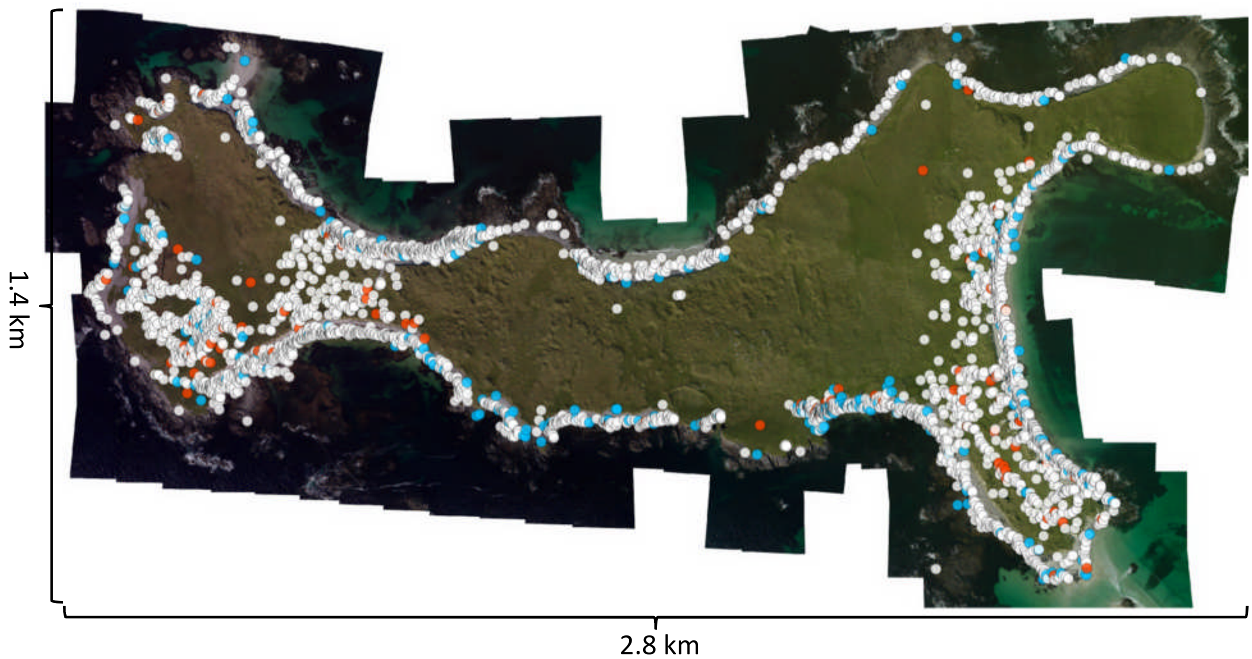


Figure 5. Ceann Iar, the second biggest of the Monach Isles in the Outer Hebrides, is the largest grey seal breeding colony in Europe (ca. 6,000 pups are born each year). This screenshot shows white-coated (white), moulted (blue) and dead pups (red) counted from approximately 200 stitched photographs taken on 7 October 2012. The composite image was stitched together and exported using Microsoft's Image Composite Editor v1.4.4®. The resulting 7.2 gigapixel PSB file (15 GB) was split into 30,000x30,000 pix TIFF tiles using Adobe Photoshop CS5®. These were then imported into Manifold GIS 8.0® for counting.

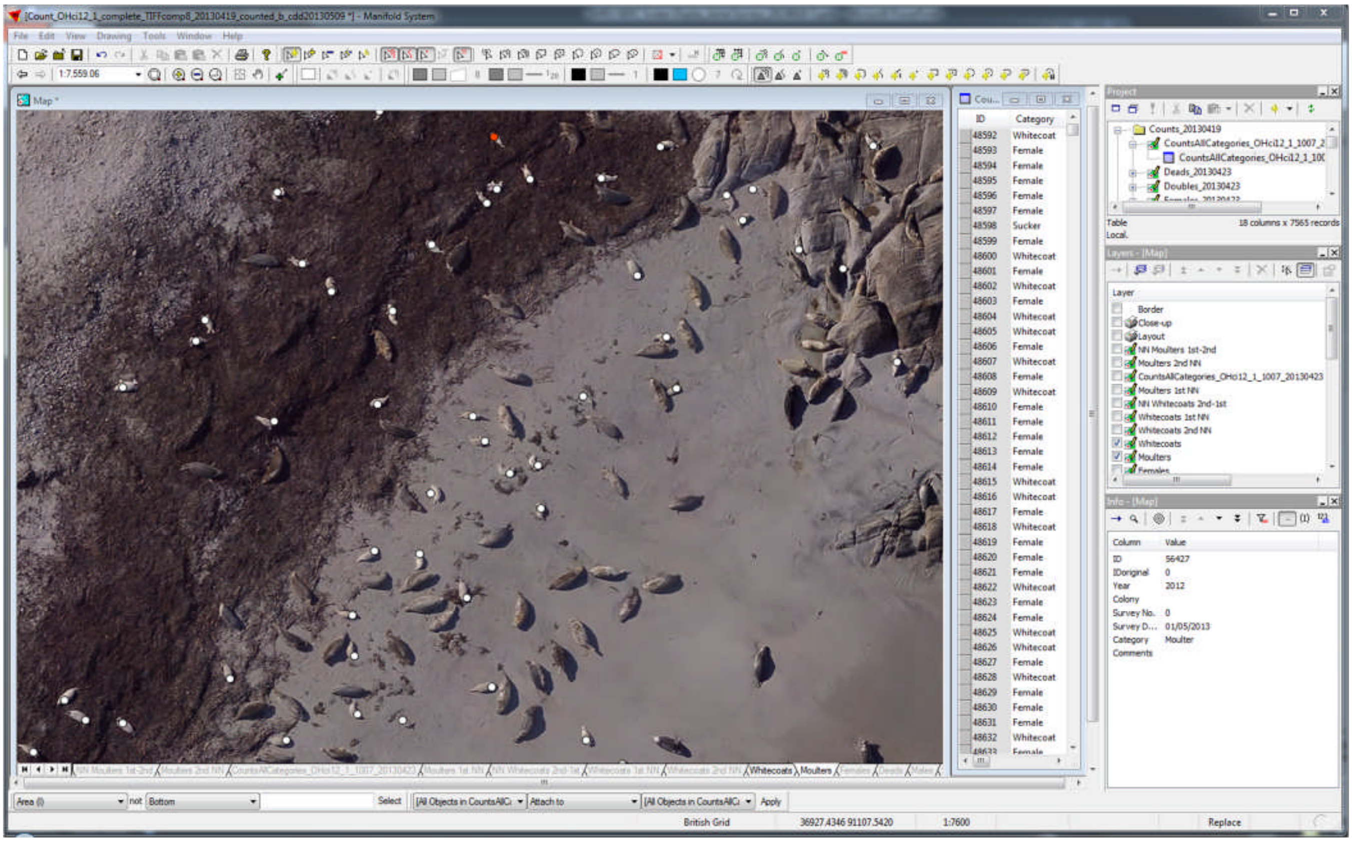


Figure 6. Manifold GIS 8.0® screenshot showing grey seal pups counted on Ceann Iar. Pups of each category (whitecoat, moulted, dead) are counted on a separate layer. The images are not geo-referenced initially but there is the potential for processing them further and thus for obtaining approximate coordinates for every pup counted.

Figure 7. Grey seal pup production at North Sea colonies with 95% confidence intervals where available. Data from the Sea Mammal Research Unit, the National Trust, Lincolnshire Wildlife Trust and Natural England.

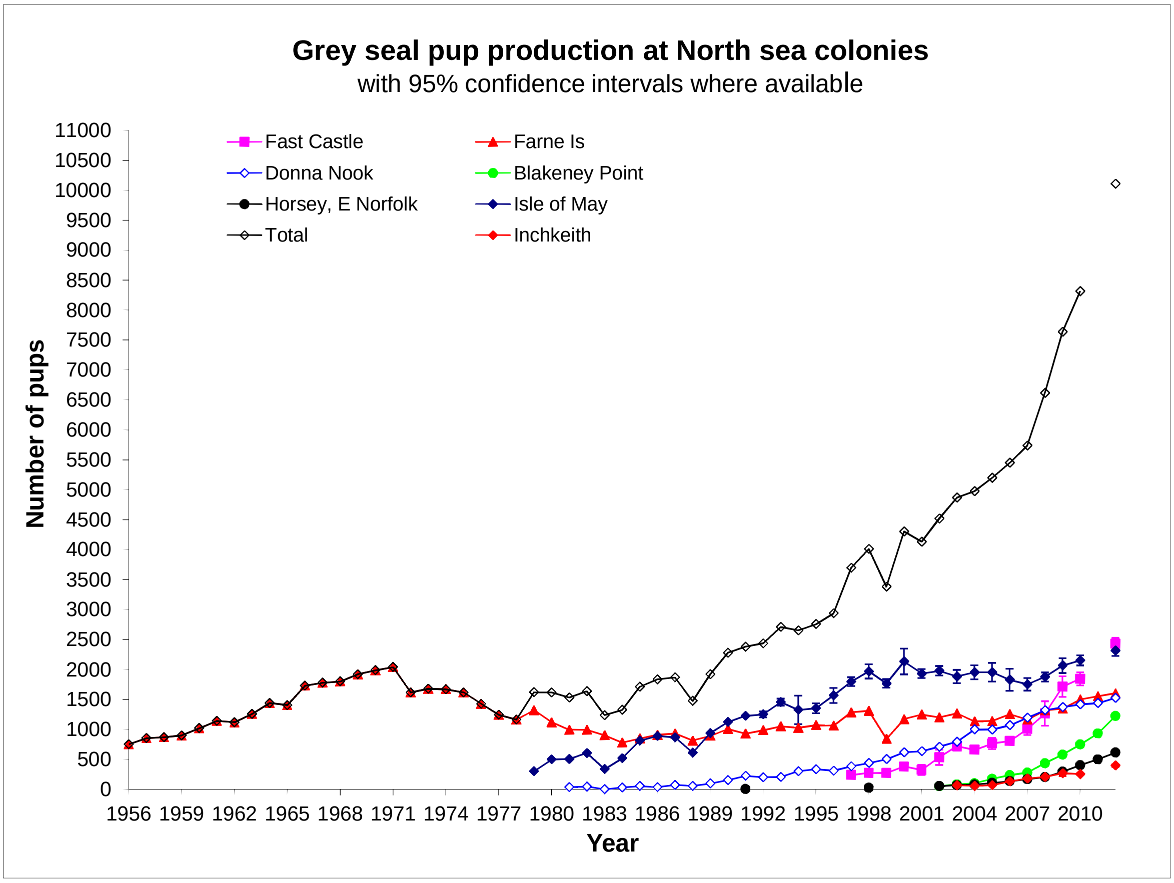


Figure 8. Total grey seal pup production at colonies in the Inner Hebrides with 95% confidence intervals. The 2012 pup production estimate is considerably higher than in previous years. This includes one new colony, Soa off Coll (with 90 pups), for the first time. Note that pup production in 2008 was used as a proxy for 2009, when a full survey could not be completed.

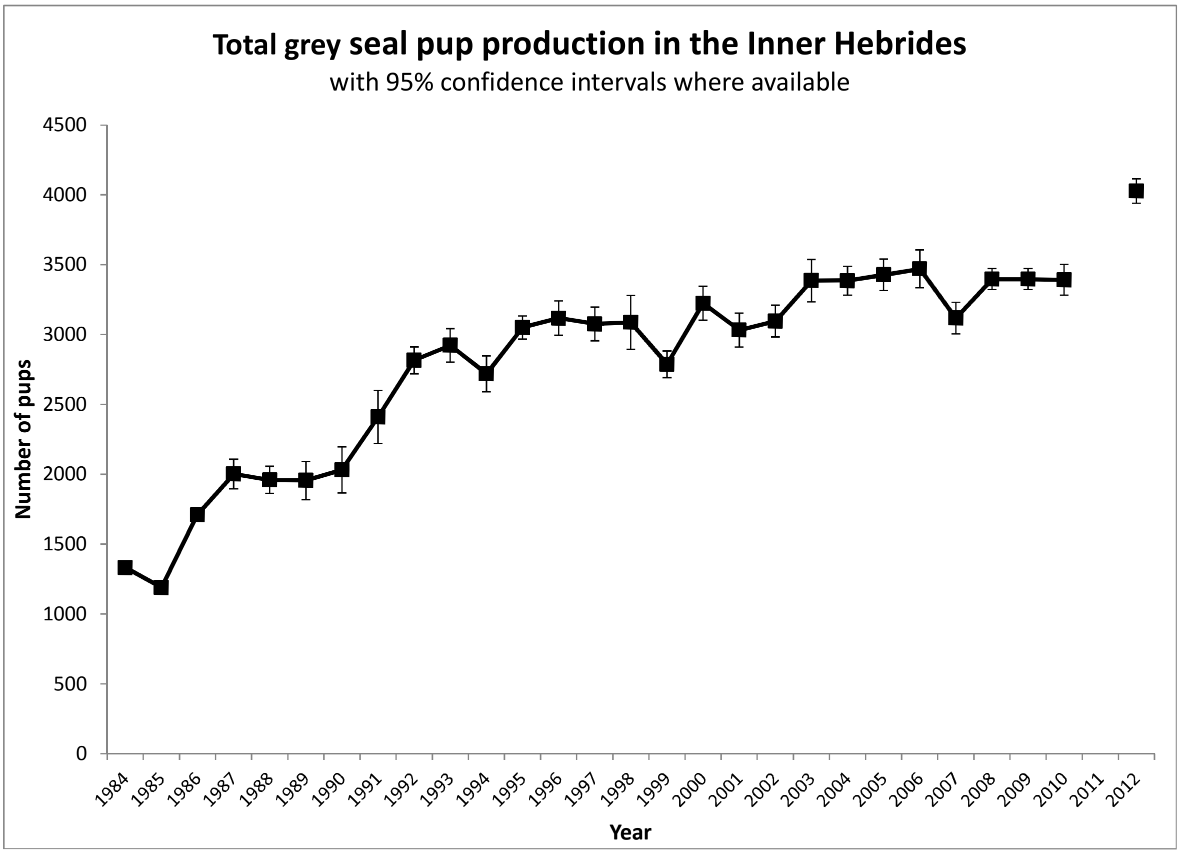


Figure 9. Grey seal pup production at individual colonies in the Inner Hebrides. Prior to 2012, total pup production in the Inner Hebrides increased very slightly between 1992 and 2010, although at a number of colonies production was steadily increasing (Gunna, Nave Island, Oronsay), at others it was steadily decreasing (Lunga, Fladda, Northern Treshnish, Soa) while at the remainder it was fairly constant (Eilean an Eoin, E. nan Ron, Oronsay Strand, Sgeir a'Chaisteil + Eirionnaich). For most, but not all, colonies there was a marked increase in 2012. Note that pup production in 2008 was used as a proxy for 2009, when a full survey could not be completed.

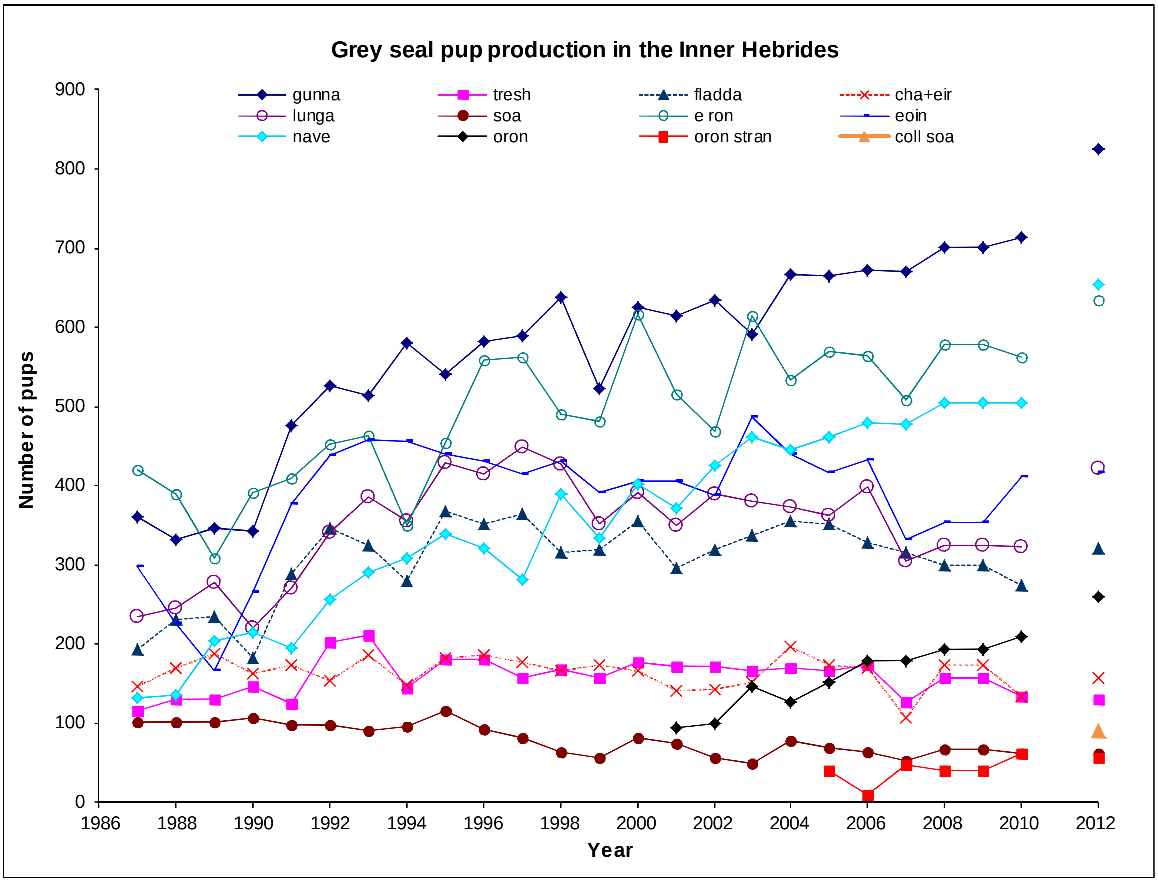
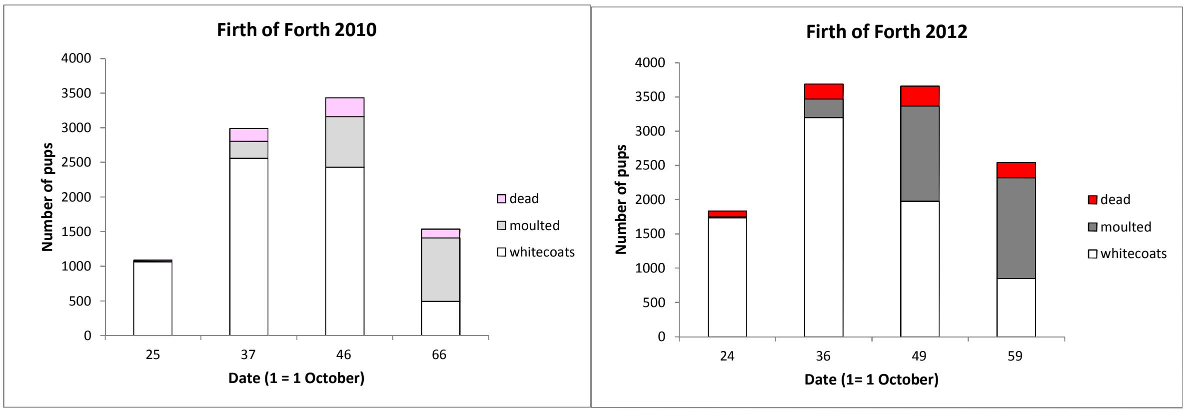


Figure 10. Comparison of the classified pup counts from 2010 and 2012 for colonies in (a) the Firth of Forth and (b) for colonies in the Inner Hebrides. The proportions of moulted to whitecoated pups on each survey are higher in 2012 than in 2010. The higher resolution digital images enabled more accurate classification of moulted pups.

(a) Firth of Forth



(b) Inner Hebrides

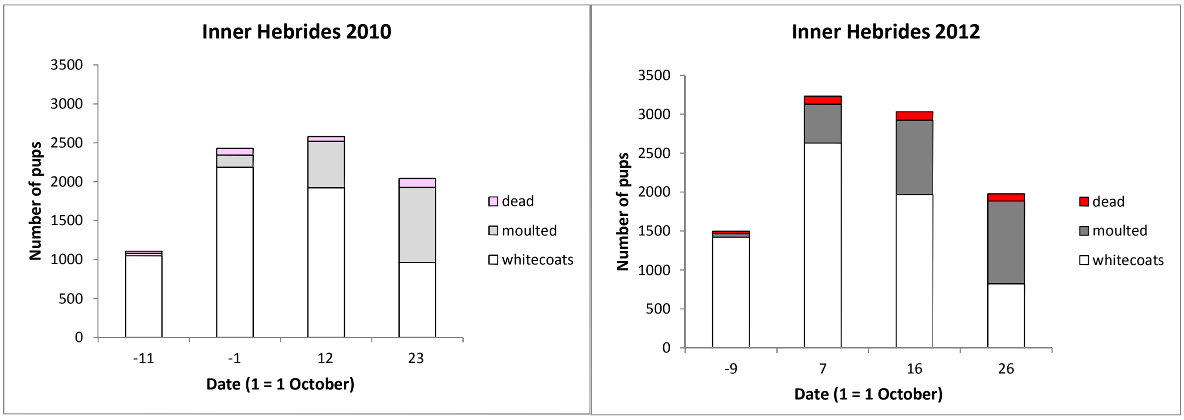


Figure 11. Pup production estimates for three colonies in the Firth of Forth, with 95% confidence intervals, using three values for the proportion of pups correctly classified as moulted. Up to 2010, a fixed proportion of 50% was used for the standard model run. Improved image quality suggested using a higher value (90%, fixed). The original 50% fixed value resulted in the lowest pup production estimate but with the highest confidence intervals. A higher value of 90% fixed resulted in increased production estimates with lower confidence intervals. Allowing the model to select its own value (0.5 free) was very similar to the 90% fixed, but with marginally lower production estimate and marginally lower confidence intervals for some colonies.

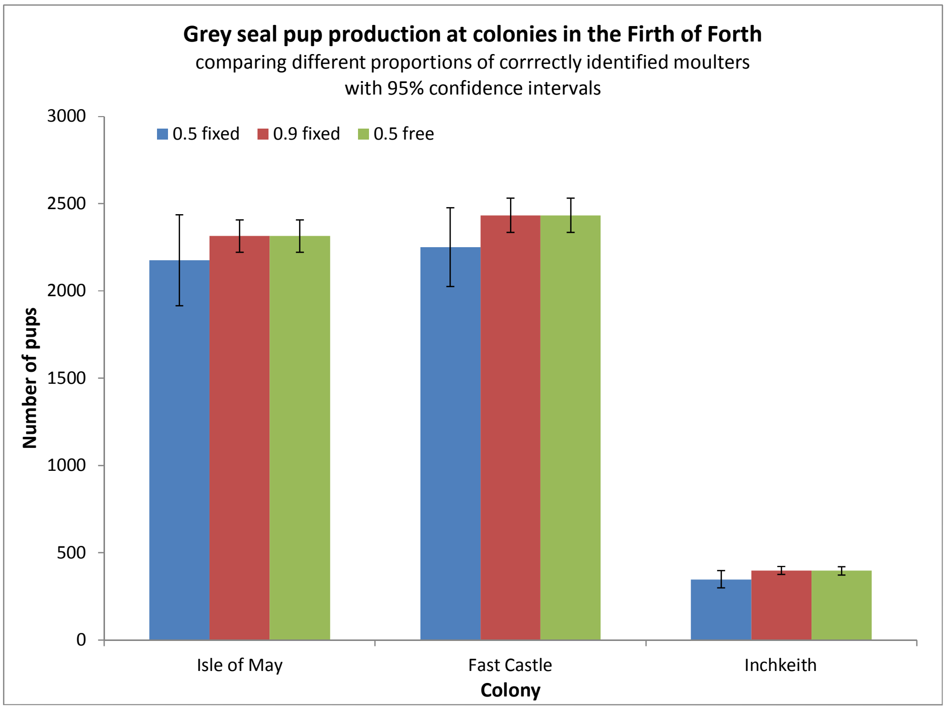
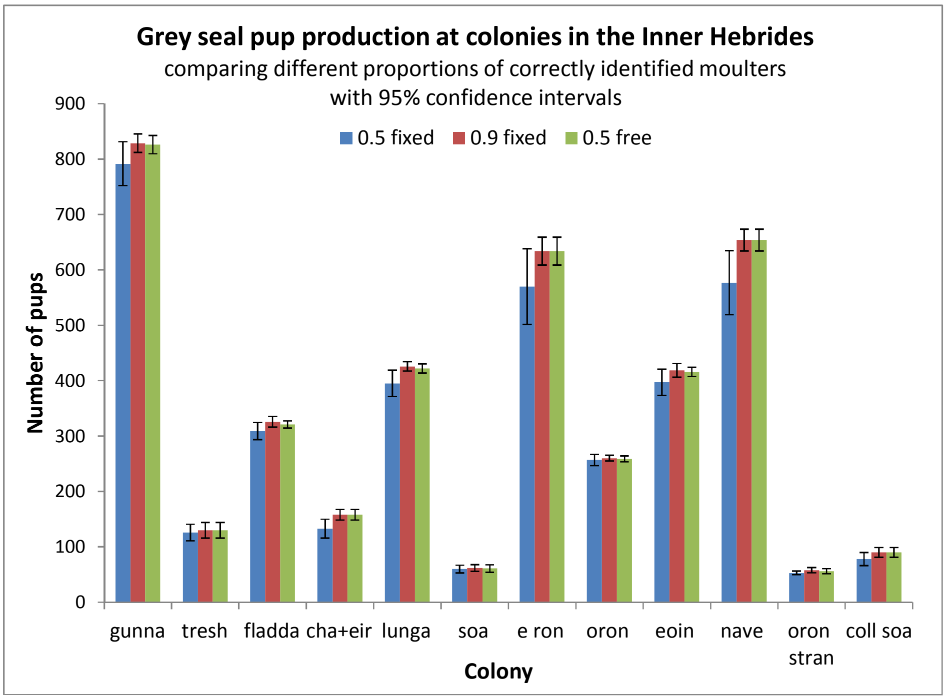


Figure 12. Pup production estimates for 12 colonies in the Inner Hebrides, with 95% confidence intervals, using three values for the proportion of pups correctly classified as moulted. Up to 2010, a fixed proportion of 50% was used for the standard model run. Improved image quality suggested using a higher value (90%, fixed). The original 50% fixed value resulted in the lowest pup production estimate but with the highest confidence intervals. A higher value of 90% fixed resulted in increased production estimate with lower confidence intervals. Allowing the model to select its own value (0.5 free) was very similar to the 90% fixed, but with marginally lower production estimate and marginally lower confidence intervals for some colonies.



Estimating the size of the UK grey seal population between 1984 and 2012, using established and draft revised priors

Len Thomas

Scottish Oceans Institute and Centre for Research into Ecological and Environmental Modelling, The Observatory, University of St Andrews, St Andrews KY16 9LZ

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 to 2010 (no pup production assessments were made in 2011, and estimates for 2012 were not available at time of writing), and (2) an independent estimate assumed to be of total population size just before the 2008 breeding season. 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 the EDDSNM model used in previous briefing papers, and used the same priors on demographic parameters that have been used since 2005. Estimated adult population size in 2012 was 100,300 (95% CI 80,700-128,100).

In addition, we undertook some additional investigations. First, we fitted the model using a set of revised priors on demographic parameters that were introduced in a 2012 briefing paper. Second, we included a prior on sex ratio, rather than assuming this value is known as in previous analyses. Third, we examined correlation in the parameter estimates. Forth, we fitted the model separately in each region to assess evidence for regionally-varying demography above that allowed by the global model. Fifth, we re-fitted the model using fecundity estimates derived directly from the long-term studies on Isle of May and North Rona to assess the sensitivity of model outputs to prior specification. Results of these investigations are presented in the paper, together with discussion of future research needs.

Introduction

This paper presents estimates of British grey seal population size and related demographic parameters, using identical the models and fitting methods to Thomas (2011), but projecting forward one more year to 2012. Models are specified using a Bayesian state space framework with informative priors on demographic parameters, and fitted using a Monte Carlo particle filter. In past briefing papers, multiple models of the population dynamics have been fitted and compared, representing differing hypotheses about the demographic parameter subject to density dependent regulation. The model where density dependence affects pup survival was found to be better supported by the data than one where density dependence affects female fecundity; hence only the former is used here.

A number of additional investigations are also undertaken, related to the priors used on demographic parameters. Lonergan (2012) introduced a revised set of priors, based on updated information and discussions within the Sea Mammal Research Unit; these were used by Thomas (2012) to assess what difference these make to the population estimates and this study is repeated here. We also investigate the consequences of using a prior on sex ratio, rather than assuming a fixed sex ratio, as in previous analyses. We investigate the use of separate regional models, rather than the current global model, and also the effect of using priors on fecundity that are derived directly from the intensive studies on Isle of May and North Rona. The reason to focus on fecundity is that, as we show, this is the parameter whose specification makes the most difference to the estimate of total population size.

Materials and Methods

Process model

The population dynamics model is described fully in Thomas and Harwood (2008) and papers cited therein (it is referred to there as the EDDSNM model). In summary, the model tracks seal population numbers in 7 age groups (pups, age 1-5 females, which do not pup, and age 6+ females, which may produce a single pup) in each of four regions (North Sea, Inner Hebrides, Outer Hebrides and Orkney). There are three population sub-processes: (1) survival, (2) ageing and pup sexing and (3) breeding. (The models of Thomas and Harwood 2008 also included movement of age 5 females between regions, but we assume no movement in the current model.) The model has 8 parameters: adult (i.e., age 1 and older) female survival, ϕ_a, maximum pup survival $\phi_{j\max}$, one carrying capacity parameter-related parameter for each region, β_1 - β_4, a parameter, ρ, that dictates the shape of the density-dependent response and fecundity (i.e., probability that an age 6+ female will birth a pup), α.

The model does not describe the dynamics of adult male seals. To obtain an estimate of total population size we followed previous briefing papers in multiplying the female population size by a fixed value of 1.73, i.e., assuming that females make up 57.8% of the adult population. However, Lonergan (2012) provides a suitable prior for this multiplier, and we also obtained results using this prior, as detailed below under Additional investigations.

Data, observation models, and priors

One source of input data was the pup production estimates for 1984-2010 from Duck (2011), aggregated into regions. These were assumed to be normally distributed with mean equal to the true pup production in each region and year, and constant coefficient of variation (CV). We followed Thomas (2011) in assuming a CV of 9.8%. (This is based on an estimate from running a simple model; it could be estimated for the EDDSNM model used here or integrated out if required (see Thomas and Harwood 2008), but previous analyses have shown results to be quite insensitive to the actual value used for observation CV.)

The second source of input data was a single estimate of adult population size of 88,300 (95% CI 75,400-105,700) obtained by Lonergan et al. (2010) from summer haulout counts and telemetry data. We followed previous briefing papers (e.g., Thomas 2012) in assuming the estimate was of population size just before the start of the 2008 breeding season, and by representing the uncertainty in the estimate (which Lonergan obtained via a nonparametric bootstrap) using a right-shifted gamma distribution.

Prior distributions for the process model parameters were the same as those used in previous briefing papers (first introduced in Thomas and Harwood 2005), and are given in Table 1. (We also did runs using alternative priors – see Additional investigations, below.) We followed Thomas and Harwood (2005) in using a re-parameterization of the model to set priors on the numbers of pups at carrying capacity in each region, denoted χ_r for region r, rather than directly on the β s. Prior distributions for the states were generated using the 1984 data, as described by Thomas and Harwood (2008).

In summary, the data and priors used here are almost identical to those used by Thomas (2011), except the observation error CV used here is the one that was estimated in that paper. We therefore expect the estimates for 2010 to be almost identical to those of Thomas (2011); the only difference here is that we are projecting the population forward one additional year, to yield population size estimates for 2012.

Fitting method

We used the particle filtering algorithm of Thomas and Harwood (2008). This involves simulating samples ("particles") from the prior distributions, projecting them forward in time according to the population model, and then resampling and/or reweighting them (i.e., "filtering") according to their likelihood given the data. An identical algorithm to that of Thomas and Harwood (2008) was used for the pup count data, and the additional adult data was included by reweighting the final output according to the likelihood of the estimated 2008 population size, as described by Thomas (2010).

The final output is a weighted sample from the posterior distribution. Many samples are required for accurate estimation of the posterior, and we generated 1,000 replicate runs of 1,000,000 samples. A technique called rejection control was used to reduce the number of samples from the posterior that were required to be stored, and the effective sample size of unique initial samples was calculated to assess the level of Monte Carlo error, as detailed in Thomas and Harwood (2008).

Additional investigations

Revised priors

We re-fitted the model using the revised priors suggested by Lonergan (2012; see Table 1), and assuming a CV on pup production of 8.9% (again, obtained by first fitting a simpler model, see Thomas 2012).

Prior on sex ratio

In calculating total population size, the above models assume a fixed multiplier of 1.73 on the estimated adult female population. However, given the independent estimate of total population size, it is possible to estimate the multiplier value, given a prior distribution. We implemented this, using the prior suggested by Lonergan (2012) (denoted ω in Table 1), which has a prior mean of 1.2 and standard deviation of 0.63. (In practice, this involved re-weighting the outputs from the previous revised priors analysis, so no additional model runs were required.)

Parameter correlations

One way to investigate the sensitivity of the model to changes in priors on the parameters is to examine the correlation in the joint posterior parameter estimates. For example, for parameters that are highly negatively correlated, changing the prior on one by decreasing its value will result in a concomitant increase in the value of the other and hence little difference in model fit or predictions. As an initial investigation we calculated pairwise correlations and produced a scatterplot of the posterior parameter values.

Regional model

The models fit above ("global models") assume that adult survival (ϕ_a), fecundity (α) and the density-dependence shape parameter (ρ) are the same in all four regions. To investigate the support for this, we re-fit the data independently in each region, using the revised priors in Table 1 but assuming a fixed sex ratio. We documented the difference in posterior parameter estimates for these four regional models compared with the global model, and the differences in estimated total population size. In this analysis, we used the pup production data alone; it would be feasible to fit a joint regional model and include the 2008 total population size estimate as data, however including the total population size estimate would reduce any differences in the final estimate of population size between this analysis and the global model analysis. Only 150 runs of 1,000,000 samples were used in each of these analyses, so results will have higher Monte Carlo error than the previous ones.

Prior on fecundity from intensively-studied populations

There are two intensively-studied populations, at Isle of May and North Rona, for which minimum fecundity rate estimates can be derived, as documented in Lonergan (2012). Values are given in Table 3 of that paper, based on unpublished work by P. Pomeroy and S. Smout. These are (for all years of data) 0.63 (95% CI 0.59-0.68) for Isle of May and 0.72 (95% CI 0.69-0.74) for North Rona. These values were fit to scaled shifted beta distributions (using a sum of squares objective function); in the event the shift parameter was estimated as being very close to 0 so beta distributions were used (see Table 1). These fitted distributions were used as priors in re-runs of the North Sea and Outer Hebrides regional models (again with 150 runs of 1,000,000 particles), assuming that the Isle of May and North Rona colonies were representative of these two regions, respectively.

Results

Monte Carlo accuracy

The effective sample size (ESS) of unique particles is a useful measure of the accuracy of the simulation. The ESS based on pup count data alone was 572.5 (Table 2), and after inclusion of the independent population estimate was 82.5. ESSs around 5 times lower lower than this have been shown in previous briefing papers to produce population and parameter estimates accurate to around 2-3 significant figures, so we should expect the estimates reported here to be accurate to at least this level.

Parameter and population estimates

Model fits to the pup production estimates are shown in Figure 1. As noted by Thomas (2011), the estimates broadly provide a reasonable fit to the pup production data, but there are some clear deficiencies: the fitted model does not adequately capture the rapid rise and sudden levelling off in pup production in the Hebrides during the early 1990s, nor levelling off in Orkney in the late 1990s; it over-estimates pup production in the North Sea in the late 1990s and early 2000s, and does not track the strong increases in pup production there in the past 3 years. Addition of the 2008 independent estimate makes little difference to this part of the model, except in the last years where the addition of the independent estimate decreases the estimated pup count slightly.

Parameter estimates are shown in Figure 2 and summarized in Table 1. The independent population size estimate causes the estimates of adult survival to increase slightly (to 0.95), maximum juvenile survival to decrease (to 0.5), and fecundity to increase slightly (to 0.96) but stay very close to the prior distribution.

Adult population size estimates are shown in Figure 3; the values for 2012 are also given in Table 3. The independent estimate for 2008 of 88,300 (with 95%CI 75,400-105,700) is lower than the value predicted for that year from pup production data alone (125,500, with 95%CI 93,400-167,400), although the credible/confidence intervals overlap. When the independent estimate is included in the population dynamics model fitting, the estimate for 2008 from this model decreases by 20% to 100,300 (95%CI 80,700-128,100). Estimates for all years from the model fit to both pup production data and the independent estimate are given in Appendix 1. The estimate from 2010 (100,000) is, as expected, very close to the estimate for 2010 (of 99,600) made by Thomas (2011) using the estimated CV that was assumed fixed in this model.

Additional investigations

Revised priors

As might be expected, use of revised priors caused differences in posterior parameter estimates (Figure 4 and Table 1). Adult survival was estimated to be higher, and maximum pup survival lower; fecundity was estimated to be higher but was, just as with the previous analysis, almost completely governed by the prior distribution. Addition of the 2008 independent population estimate caused the estimate of adult survival to increase still further (to an implausible 0.985) and maximum pup survival to decrease further (to an also unlikely 0.3), while fecundity was also slightly higher.

Estimates of total population size are somewhat lower without the independent population estimate (cf. blue lines on Figure 3 and 5), which is unsurprising given the revised prior (and posterior) on fecundity is lower. The addition of the independent population size estimate again lowers the total population size estimate, and the result is slightly lower than with the old priors (cf. red lines on Figures 3 and 5).

Prior on sex ratio

With the addition of a prior on sex ratio, posterior estimates of survival remained closer to more realistic values, even with the addition of the 2008 independent population estimate (Figure 6 and Table 1). The posterior on fecundity also remained close to the prior with the addition of the independent estimate. This is because even without this estimate, the estimated total population size was close to that of the independent estimate (Figure 7, blue line); this meant that little alteration in the demographic parameters was required when the independent estimate was introduced. Note that this includes the posterior on the sex ratio parameter – this could potentially be greatly affected by the independent estimate, but because the estimates of total population size from the population dynamics model and independent estimate were so congruent, it was little changed by introduction of the independent estimate into the analysis. The resulting estimate of total population size was similar to that without the independent estimate (Figure 7), but rather more precise (dashed lines in Figure 7 show 95% posterior CI; see also Table 4).

Parameter correlations

The scatterplot of posterior parameter estimates from the previous analysis is shown in Figure 8. Correlations of greater than 0.7 were observed between adult and pup survival (ϕ_a and ϕ_p, -0.94), carrying capacity in the Inner and Outer Hebrides (ψ_{ih} and ψ_{oh}, 0.83) and between adult survival and carrying capacity in the Inner Hebrides (ϕ_a and ψ_{ih}, 0.71). Other, weaker, relationships were also evident (Figure 8) particularly within the carrying capacity parameters and between these and adult survival.

The fact that adult and juvenile survival are so strongly correlated implies that changes in the prior, and therefore posterior, for one will be compensated for by an opposite change in the posterior for the other, thereby having relatively little effect on estimates of total population size (given the constraint of the independent estimate). This was indeed seen when comparing the old and revised priors analyses. By contrast fecundity is not correlated with other parameter estimates; this coupled with the fact that the prior on fecundity is informative to the extent it is not changed greatly by the data in any of the analyses to date means that the prior chosen for fecundity can be expected to have a very strong influence on the estimates of total population size.

Regional models

Fits to the pup production data from the regional models (not shown) were largely similar to the global model, although the fit to Orkney data was somewhat better, with a more rapid levelling-off of pup production in recent years, better matching the data. Posterior parameter estimates for the survival and fecundity parameters were, on the whole, rather similar to those from the global model (Table 5), although the adult survival estimate was somewhat lower (0.94) than the other regions (0.96-0.97) and the global model (0.96). Estimates of carrying capacity (Table 5) were considerably higher in the North Sea region, and were effectively infinity in the Outer Hebrides – the latter is inexplicable and may indicate an issue with the model fitting that needs to be investigated further.

Estimated adult population sizes by region were not greatly different from the global model (Table 6), with the total population size estimate summed across regions being approximately 2% lower (123,000 for the global model and 120,700 for the regional model).

Prior on fecundity from intensively-studied populations

As might be expected given previous analyses, the posterior estimates on fecundity were close to the priors used in these analyses (Table 5), and these produced corresponding changes in the estimates of adult population size for the two regions affected (Table 6): estimates for North Sea were approximately 15% higher and for Outer Hebrides 10% higher. Since these two regions together comprise around 50-60% of the total population, the effect on total adult population size was more modest – an approximate 7% increase (to 129,500).

Discussion

Main analysis

Estimated total population sizes for 1983-2011 are very similar to those reported by Thomas (2011) for the EDDSNM model, which is to be expected given that the same data and priors were used. Pup counts were undertaken in 2012, and will be included in future model fits once available – we anticipate that these will change our estimates of population trajectory somewhat.

The relative weight of the independent estimate and pup production data depends in part on the coefficient of variation on the pup production data. Here this was assumed fixed, but methods exist to allow this to be a model parameter, with some prior distribution, and then integrate it out of the estimates. Although this is likely to produce very similar results, it is a neater solution, and hence is to be preferred.

Additional investigations

We have made an initial investigation of the sensitivity of the total population size estimate to changes in priors on demographic parameters. The strong inverse correlation between posterior estimates of adult and pup survival means that changes in the priors on these parameters have little effect on estimated total population size. By contrast, the fecundity parameter is not correlated with the other parameters, and the prior is also highly informative in the sense that the posterior is almost identical to the prior in all of the analyses performed here, meaning that the data carry little additional information about this parameter; changes in this parameter have a strong effect on population size estimates. We also found that allowing sex ratio to be a parameter, rather than assuming it to be fixed, had a strong effect on estimated population size. It is interesting to note that the population estimates produced by the population dynamics model fit to pup production data and with revised priors including a prior on sex ratio were very similar to the independent population size estimate – this perhaps provides some confirmation for the choice of priors. More work, however, is required to refine the prior distributions, and future work should focus on the priors for fecundity and sex ratio.

We have not investigated the sensitivity of population size estimates to priors on the carrying capacity parameters – this can be expected to be quite low because these parameters are either reasonably well specified by the data (i.e., the priors are changed considerably by the data) or, in the case of the North Sea region, which does not appear to be close to carrying capacity, the posterior estimate is expected to have little effect on the estimated population size. Nevertheless, these parameters should be investigated.

Apart from simply varying the prior distributions, other means exist for quantifying prior sensitivity. For example, Millar (2004) quantified sensitivity of parameter posteriors using a measure of the differential of the posterior mean with respect to prior parameters; this approach could potentially be extended to quantifying sensitivity of the posterior on measures that are not explicit model parameters, but are derived measures, such as population size.

The regional models did not produce results that were substantially different from the global model, suggesting that further investigation of this topic should be a secondary concern. Despite this, including the four regions within the global model seems useful, not least because regional estimates of total population size are useful for management purposes.

Data on pup production is now collected only every second year, with estimates for 2012 expected to be available in the near future. One potential future refinement would be to incorporate the pup production estimation process within the Bayesian framework used here to fit population dynamics models. This has the potential benefit of allowing the statistical uncertainty arising from pup production estimation to cascade naturally into the population dynamics modelling, rather than through the use of a measurement error parameter as happens currently. It is this measurement error parameter, together with the estimated uncertainty on the independent estimate of population size that controls the relative influence of the population dynamics model and the independent estimate on the final population size estimate. With the revised priors, the population dynamics model and the independent estimate produce similar results, and so the weighting of each is not important. Also, it seems unlikely that the weighting given to the population dynamics model would be much different from that currently used – hence this refinement is also considered to be of secondary importance.

In conclusion, the main priority for future work is to refine the priors on fecundity and sex ratio, and we expect to be able to report on this in future briefing papers.

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Table 1. Prior parameter distributions and summary of posterior distribution. (The two parameters of the gamma distribution specified here are shape and scale respectively.) Posterior summaries are all from analyses that use both 1984-2010 pup production estimates and the 2008 total population estimates.

	Main analysis			Additional investigations					
	Old priors			Revised priors			Revised priors with sex ratio not fixed		
Parameter	Prior distribution	Prior mean (SD)	Posterior mean (SD)	Prior distribution	Prior mean (SD)	Posterior mean (SD)	Prior distribution	Prior mean (SD)	Posterior mean (SD)
adult survival ϕ_a	Be(22.05,1.15)	0.95 (0.04)	0.95 (0.016)	0.8+0.2*Be(1.6,1.2)	0.91 (0.05)	0.99 (0.01)	same as previous		0.95 (0.03)
pup survival ϕ_j	Be(14.53,6.23)	0.70 (0.10)	0.50 (0.10)	Be(2.87,1.78)	0.62 (0.20)	0.30 (0.07)	same as previous		0.57 (0.18)
fecundity α_{max}	Be(22.05,1.15)	0.95 (0.04)	0.96 (0.03)	0.6+0.4*Be(2,1.5)	0.83 (0.09)	0.89 (0.06)	same as previous		0.80 (0.09)
dens. dep. ρ	Ga(4,2.5)	10 (5)	4.55 (1.33)	same as previous		7.47 (3.69)	same as previous		4.77 (2.05)
NS carrying cap. χ_1	Ga(4,2500)	10000 (5000)	8900 (2530)	same as previous		10100 (3370)	same as previous		10800 (3270)
IH carrying cap. χ_2	Ga(4,1250)	5000 (2500)	3270 (274)	same as previous		3280 (11800)	same as previous		3310 (247)
OH carrying cap. χ_3	Ga(4,3750)	15000 (7500)	12100 (717)	same as previous		11800 (1130)	same as previous		12200 (742)
Ork carrying cap. χ_4	Ga(4,10000)	40000 (20000)	19500 (2990)	same as previous		20100 (2670)	same as previous		20800 (2920)
observation CV ψ	Fixed	0.098 (0)	-	Fixed	0.89 (0)	-	same as previous		-
sex ratio ω	Fixed	1.73 (0)	-	same as previous		-	1+Ga(0.1,2)	1.2 (0.63)	1.2 (0.13)

Table 2. Number of particles simulated (K), number saved after final rejection control step (K*), number of unique ancestral particles (U), effective sample size of unique particles from pup count data alone(ESS_{u1}), and with pup production data and the independent total population estimate (ESS_{u2}). Only the global model runs are shown; sample sizes for the regional models were considerably smaller.

Model	*K* ($x10^7$)	*K** ($x10^7$)	*U* ($x10^4$)	ESS_{u1}	ESS_{u2}
EDDSNM Old priors	1000	12.4	24.0	572.5	82.3
EDDSNM New priors	1000	18.0	18.8	500.7	117.2
EDDSNM New priors, estimated sex ratio	n/a				358.6

Table 3. Estimated size, in thousands, of the British grey seal population at the start of the 2012 breeding season, derived from models fit to pup production data from 1984-2010 and the additional total population estimate from 2008, using the old parameter priors. Numbers are posterior means with 95% credible intervals in brackets.

	Pup production data alone	Pup production data and 2008 population estimate
North Sea	26.4 (17.5 36.5)	20.3 (14.5 30.3)
Inner Hebrides	8.9 (7.2 10.9)	7.5 (6.2 9.0)
Outer Hebrides	33.3 (26.8 40.0)	28.0 (24.3 33.2)
Orkney	56.9 (41.9 80.0)	44.4 (35.8 55.6)
Total	125.5 (93.4 167.4)	100.3 (80.7 128.1)

Table 4. Estimated size, in thousands, of the British grey seal population at the start of the 2012 breeding season, using a variety of parameter priors. Numbers are posterior means with 95% credible intervals in brackets.

Total	Pup production data alone	Pup production data and 2008 population estimate
Old priors	125.5 (93.4 167.4)	100.3 (80.7 128.1)
Revised priors	123 (83.9 179.5)	94.2 (76.5 117)
Revised priors with estimated sex ratio	85.3 (54.4 133.1)	88.8 (70.9 111.7)
Regional model (using revised priors)	120.7 (no CI calculated)	-
Regional model (using revised priors and priors on fecundity for NS and OH from intensively studied populations)	129.5 (no CI calculated)	-

Table 5. Prior parameter distributions and summary of posterior distribution for the regional models. (The two parameters of the gamma distribution specified here are shape and scale respectively.) Posterior summaries are all from analyses that use only 1984-2010 pup production estimates.

	Revised priors, global model			Regional model (priors same as “Revised priors” analysis)				Regional model (fecundity priors from intensively studied populations)					
				North Sea	Inner Hebrides	Outer Hebrides	Orkney	North Sea			Outer Hebrides		
Parameter	Prior distribution	Prior mean (SD)	Posterior mean (SD)	Posterior mean (SD)	Posterior mean (SD)	Posterior mean (SD)	Posterior mean (SD)	Prior distribution	Prior mean (SD)	Posterior mean (SD)	Prior distribution	Prior mean (SD)	Posterior mean (SD)
adult survival ϕ_a	0.8+0.2*Be(1.6,1.2)	0.91 (0.05)	0.96 (0.03)	0.94 (0.03)	0.97 (0.03)	0.96 (0.04)	0.97 (0.02)	same as previous		0.95 (0.02)	same as previous		0.96 (0.03)
pup survival ϕ_j	Be(2.87,1.78)	0.62 (0.20)	0.51 (0.20)	0.63 (0.18)	0.61 (0.18)	0.57 (0.20)	0.60 (0.17)	same as previous		0.66 (0.17)	same as previous		0.58 (0.20)
fecundity $\alpha_{\max}$	0.6+0.4*Be(2,1.5)	0.83 (0.09)	0.81 (0.09)	0.83 (0.09)	0.83 (0.09)	0.82 (0.09)	0.82 (0.09)	Be(279,161)	0.63 (0.02)	0.64 (0.02)	Be(886,355)	0.71 (0.01)	0.71 (0.01)
dens. dep. ρ	Ga(4,2.5)	10 (5)	5.35 (2.76)	10.5 (5)	4.9 (2.6)	6.93 (3.94)	5.72 (3.25)	same as previous		10 (4.7)	same as previous		7.06 (3.87)
ns carrying cap. χ_1	Ga(4,2500)	10000 (5000)	10800 (3410)	25200 (30100)				same as previous		27000 (37200)	same as previous		
ih carrying cap. χ_2	Ga(4,1250)	5000 (2500)	3300 (266)		3400 (550)			same as previous			same as previous		
oh carrying cap. χ_3	Ga(4,3750)	15000 (7500)	12100 (860)			1E34		same as previous			same as previous		12200 (11700)
ih carrying cap. χ_4	Ga(4,10000)	40000 (20000)	20800 (3100)				19600 (5250)	same as previous			same as previous		
observation CV ψ	Fixed	0.098 (0)	-	-	-	-	-	same as previous		-	same as previous		-
sex ratio ω	Fixed	1.73 (0)	-	-	-	-	-	same as previous		-	same as previous		-

Table 6. Estimated size, in thousands, of the British grey seal population at the start of the 2012 breeding season by region for the global model and the regional models, using revised priors. Numbers are posterior means with 95% credible intervals in brackets.

	Global model	Regional model	Regional model, with priors for NS and OH from intensively studied populations
North Sea	26.1 (15.8 39.6)	32.3 (18.2 44)	37.5 (22.1 48.1)
Inner Hebrides	8.8 (6.2 12.1)	8.2 (6 11.5)	same as previous
Outer Hebrides	32.7 (23.5 44.3)	33.3 (21.4 54.8)	36.7 (26.8 58.5)
Orkney	55.5 (38.4 83.5)	46.9 (34.1 64.1)	same as previous
Total	123 (83.9 179.5)	120.7 (CI not calculated)	129.5 (CI not calculated)

Figure 1. Posterior mean estimates of pup production (solid lines) and 95%CI (dashed lines) from the model of grey seal population dynamics, fit to pup production estimates from 1984-2010 (circles) and a total population estimate from 2008, using the old parameter priors. Blue lines show the fit to pop production estimates alone; red lines show the fit to pup production estimates plus the total population estimate.

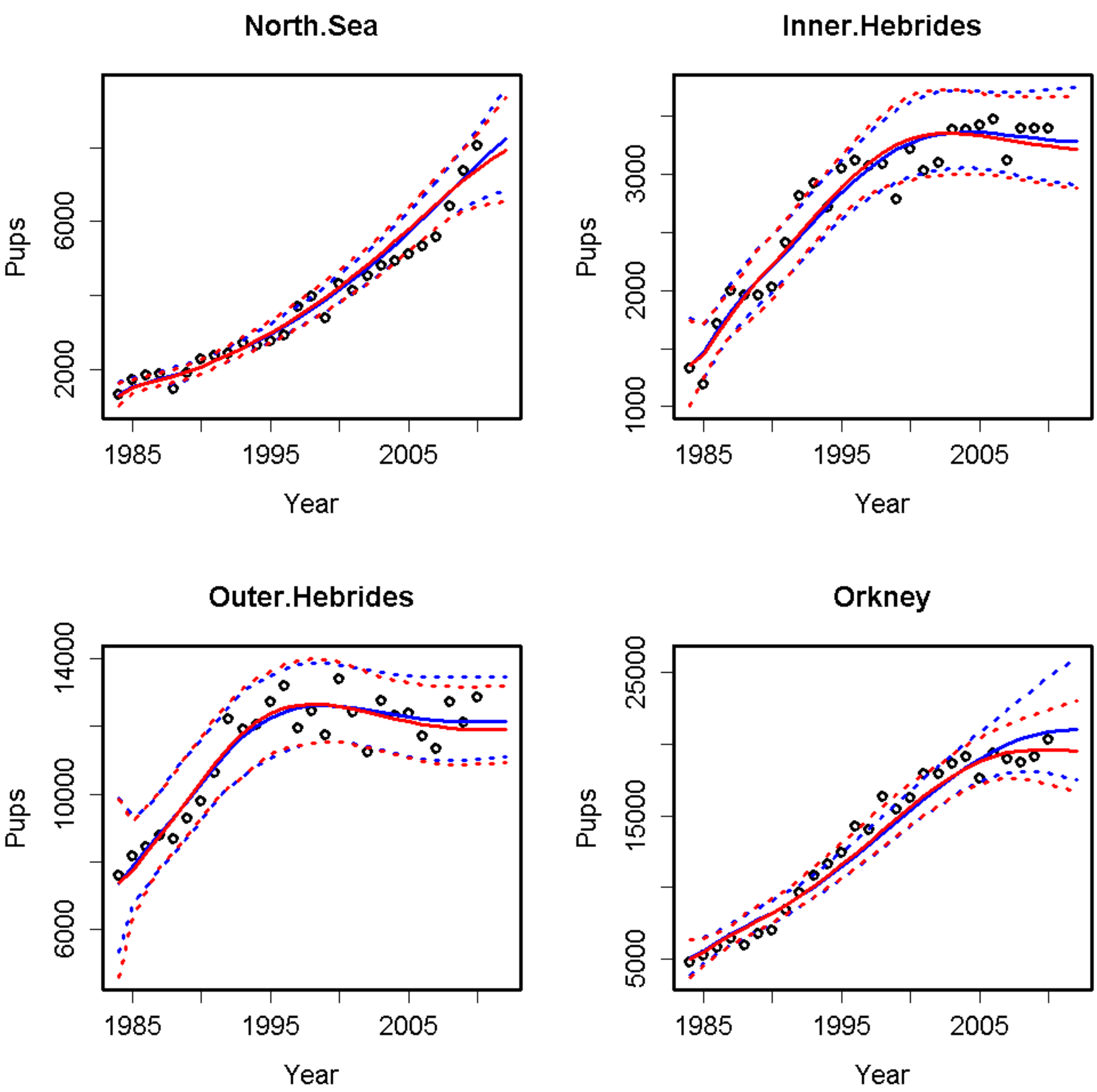
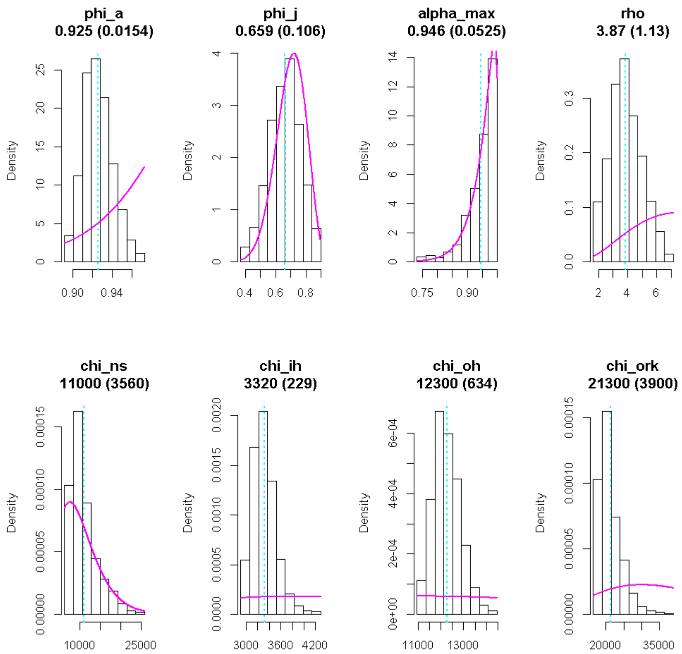


Figure 2. Posterior parameter distributions (histograms) and priors (solid lines) for the model of grey seal population dynamics, fit to pup production estimates from 1984-2010 and a total population estimate from 2008, using the old parameter priors. The vertical line shows the posterior mean; its value is given in the title of each plot after the parameter name, with the associated standard error in parentheses.

(a) Pup production data alone



(b) Pup production data and 2008 population estimate

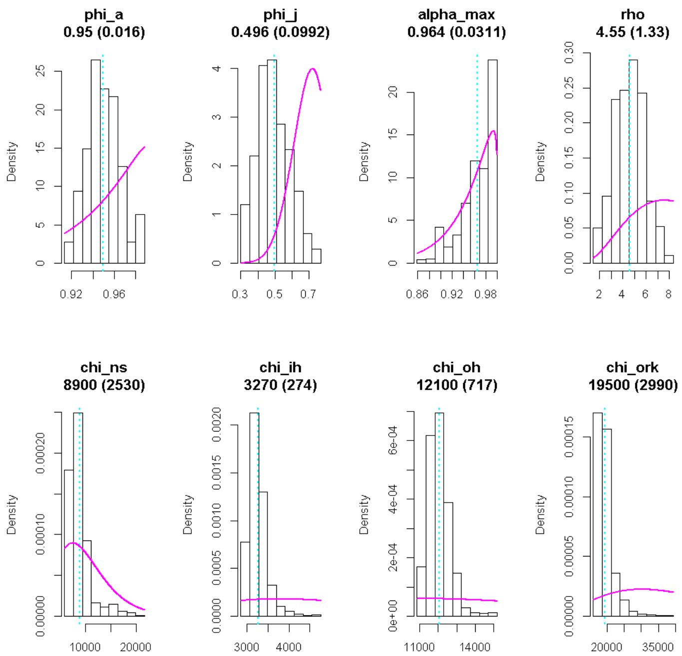


Figure 3. Posterior mean estimates (solid lines) and 95%CI (dashed lines) of total population size in 1984-2012 from the model of grey seal population dynamics, fit to pup production estimates from 1984-2010 and a total population estimate from 2008 (circle, with horizontal lines indicating 95% confidence interval on the estimate) , using the old parameter priors. Blue lines show the fit to pop production estimates alone; red lines show the fit to pup production estimates plus the total population estimate.

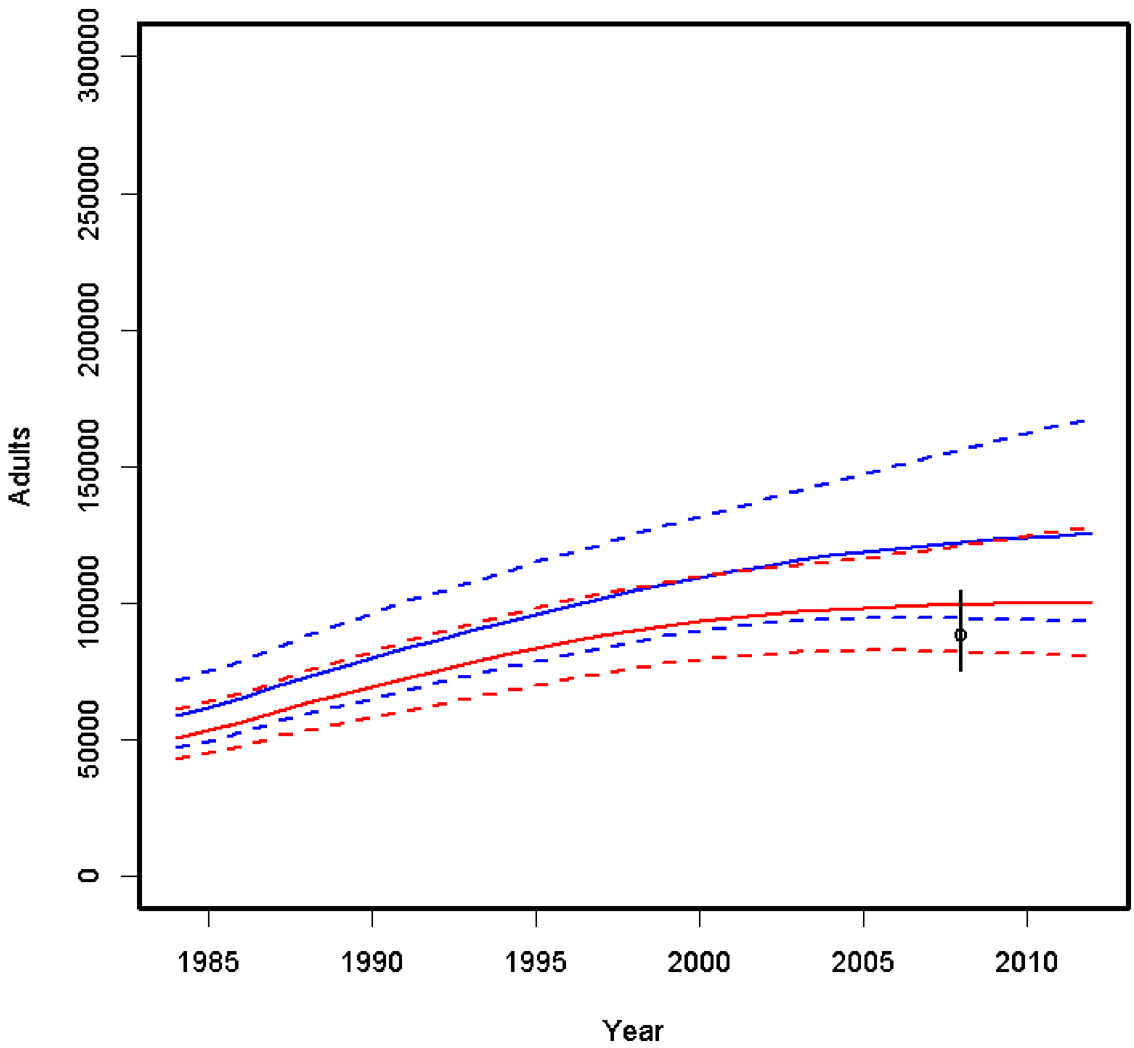
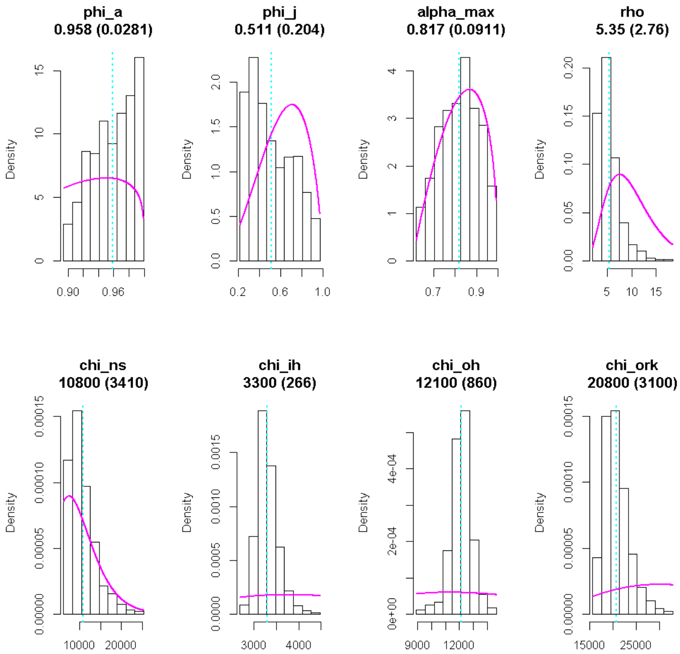


Figure 4. Prior (histograms) and posterior (solid lines) parameter estimates obtained using the revised priors. See Figure 2 legend for further explanation of the plots.

(a) Pup production data alone



(b) Pup production data and 2008 population estimate

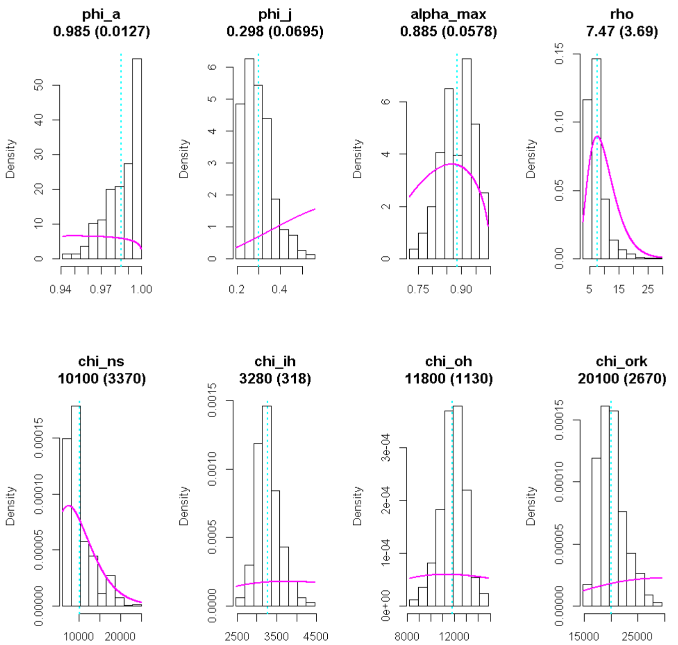


Figure 5. Posterior mean estimates (solid lines) and 95%CI (dashed lines) of total population size obtained using revised priors. See figure 3 legend for further explanation of the plot.

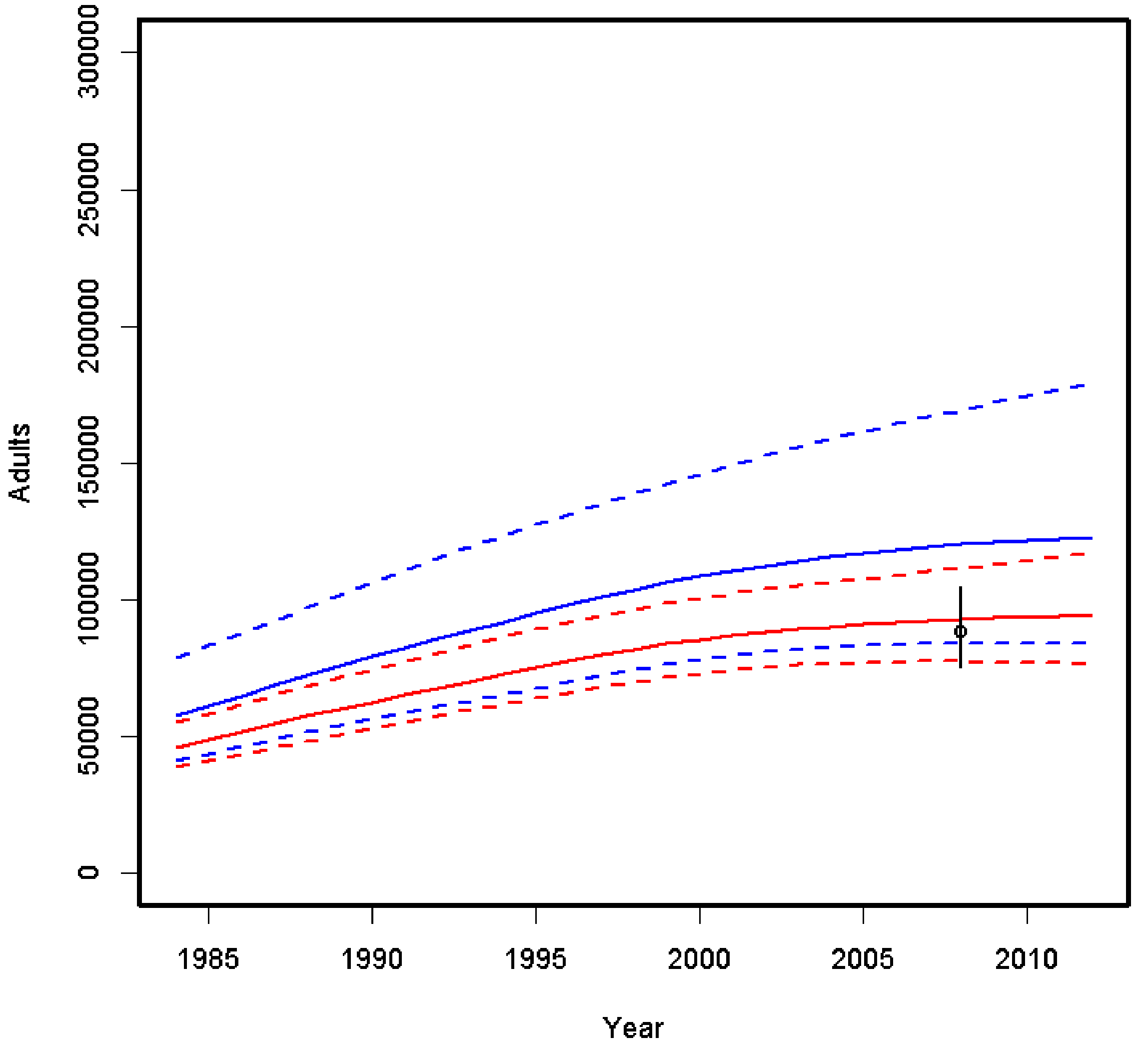
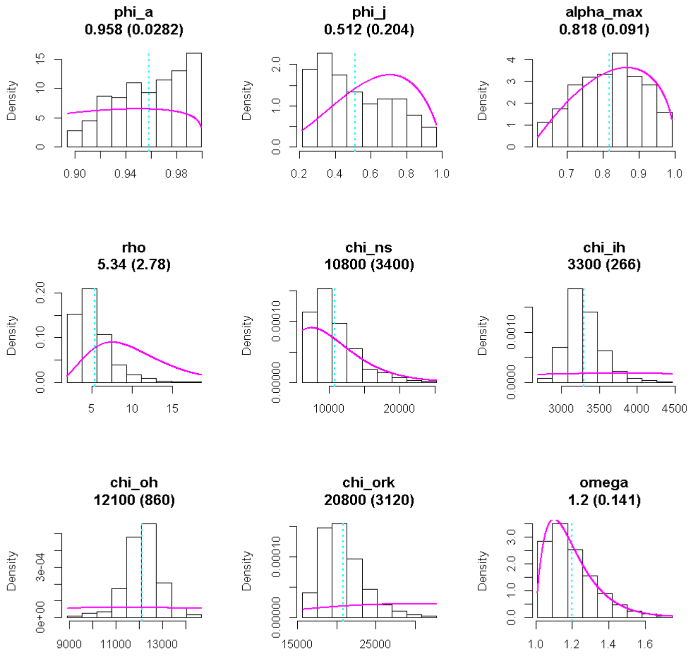


Figure 6. Prior (histograms) and posterior (solid lines) parameter estimates obtained using the revised priors, including a prior on sex ratio. See Figure 2 legend for further explanation of the plots.

(a) Pup production data alone



(b) Pup production data and 2008 population estimate

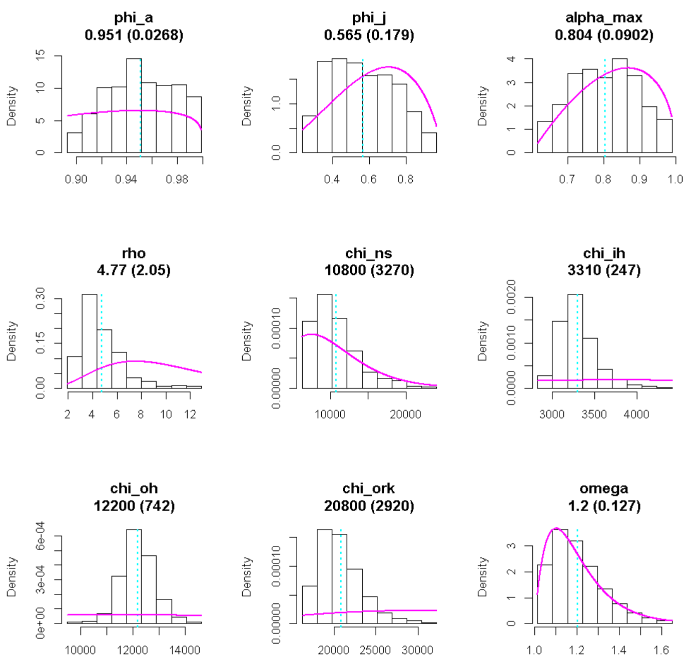


Figure 7. Posterior mean estimates (solid lines) and 95%CI (dashed lines) of total population size obtained using revised priors including a prior on sex ratio. See figure 3 legend for further explanation of the plot.

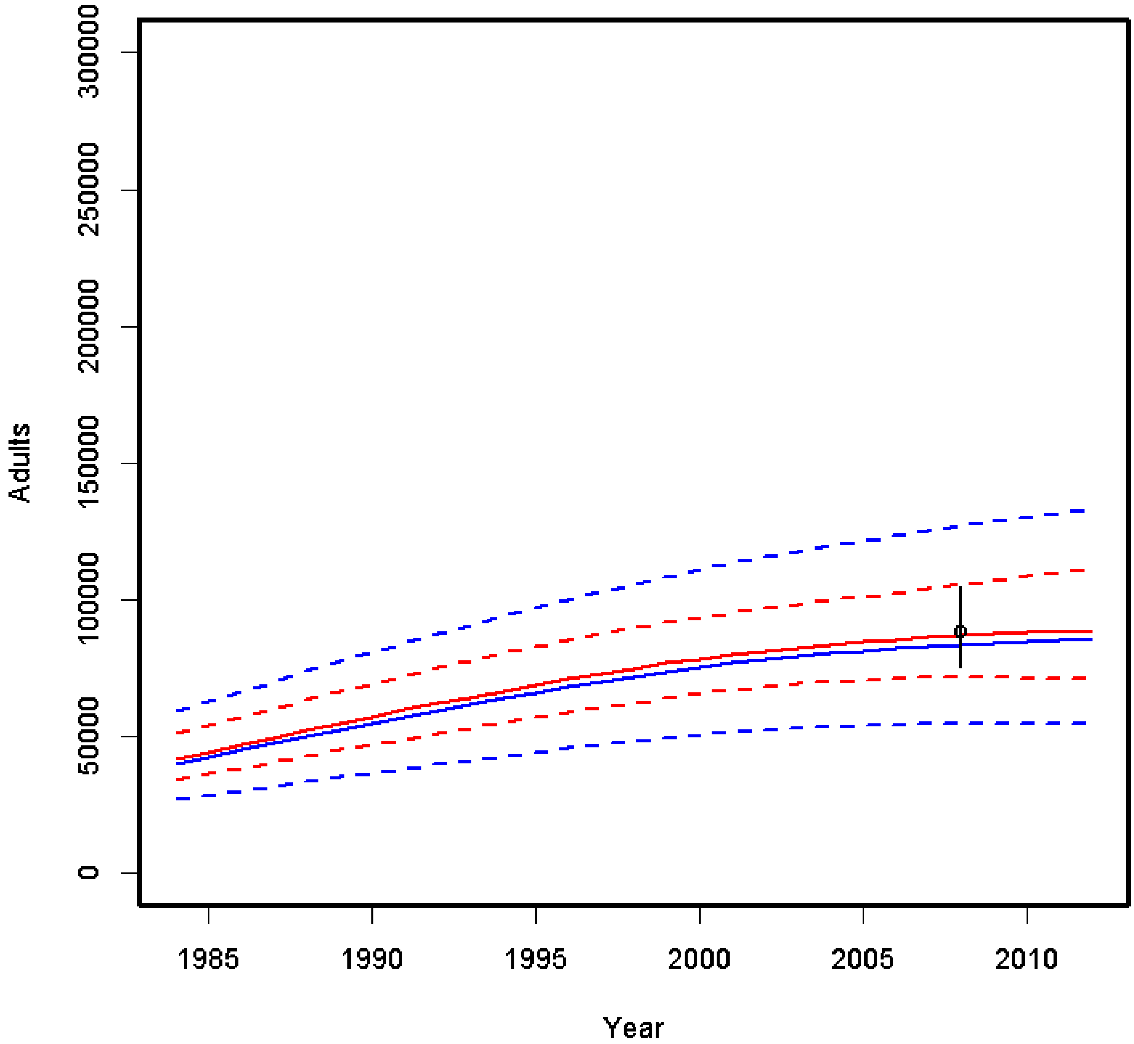
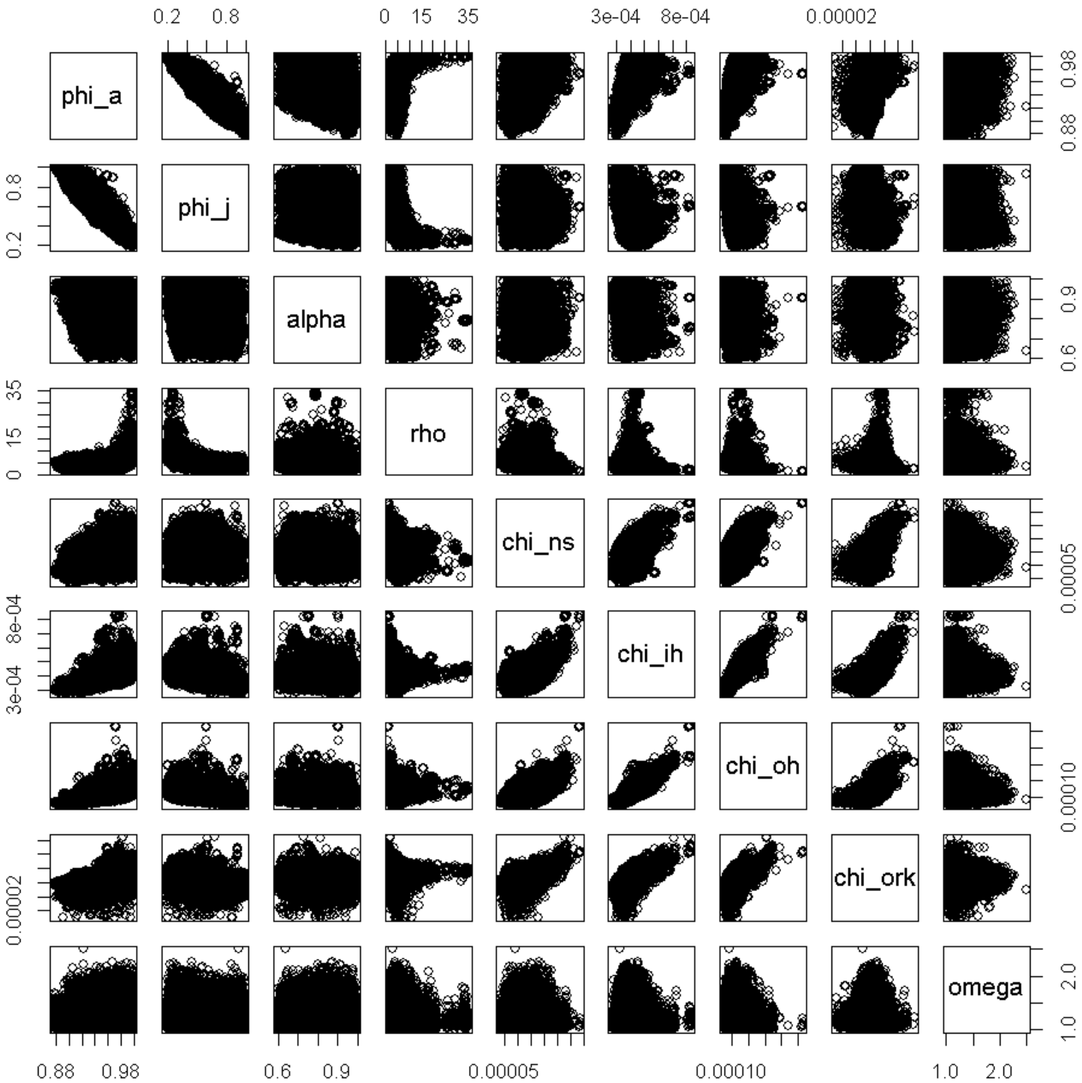


Figure 8. Scatterplot of posterior parameter estimates obtained using the revised priors, including a prior on sex ratio.



Appendix

Estimates of total population size, in thousands, at the beginning of each breeding season from 1984-2012, made using the model of British grey seal population dynamics fit to pup production estimates and a total population estimate from 2008, and using the old priors. Numbers are posterior means followed by 95% credible intervals in brackets.

Year	North Sea	Inner Hebrides	Outer Hebrides	Orkney	Total
1984	4.5 (3.9 5.3)	4.9 (4.2 5.9)	22.9 (19.6 28)	17.9 (15.1 21.6)	50.2 (42.7 60.9)
1985	4.8 (4.1 5.7)	5.2 (4.5 6.2)	24.1 (20.6 29.4)	19.1 (16.1 22.8)	53.2 (45.4 64.1)
1986	5.2 (4.5 6.1)	5.5 (4.8 6.5)	25.4 (21.4 30.5)	20.4 (17.2 24)	56.5 (47.8 67.2)
1987	5.6 (4.9 6.6)	5.8 (5 6.8)	26.5 (22.7 31.8)	21.9 (18.4 25.8)	59.8 (51 71)
1988	6.1 (5.2 7.1)	6.1 (5.3 7.2)	27.5 (23 33)	23.5 (19.8 27.6)	63.3 (53.4 75)
1989	6.5 (5.7 7.7)	6.4 (5.5 7.6)	28.3 (23.4 33.8)	25.2 (21.4 29.6)	66.4 (56 78.6)
1990	7 (6.1 8.2)	6.7 (5.7 7.9)	28.8 (23.8 34.6)	27 (22.8 31.6)	69.5 (58.3 82.3)
1991	7.5 (6.5 8.8)	7 (5.8 8.3)	29.2 (24.2 35.1)	28.8 (24.3 33.6)	72.5 (60.7 85.7)
1992	8 (6.9 9.4)	7.2 (5.9 8.6)	29.4 (24.4 35.3)	30.7 (25.8 35.8)	75.4 (63 89.1)
1993	8.6 (7.4 10.1)	7.4 (6 8.8)	29.5 (24.5 35.4)	32.6 (27.4 38)	78.1 (65.3 92.4)
1994	9.2 (7.9 10.8)	7.6 (6.1 9.1)	29.5 (24.7 35.2)	34.5 (29 40.2)	80.8 (67.7 95.3)
1995	9.9 (8.5 11.6)	7.7 (6.1 9.3)	29.3 (24.7 34.9)	36.4 (30.6 42.4)	83.3 (69.9 98.1)
1996	10.5 (9 12.4)	7.8 (6.2 9.4)	29.1 (24.8 34.5)	38.2 (32.2 44.5)	85.7 (72.1 100.8)
1997	11.2 (9.6 13.2)	7.8 (6.2 9.4)	28.9 (24.8 34.1)	39.9 (33.7 46.6)	87.9 (74.3 103.3)
1998	12 (10.1 14.1)	7.8 (6.2 9.4)	28.7 (24.8 33.8)	41.4 (35.1 48.5)	89.9 (76.3 105.7)
1999	12.7 (10.8 14.9)	7.8 (6.2 9.4)	28.4 (24.9 33.4)	42.7 (36.2 50)	91.7 (78.1 107.8)
2000	13.5 (11.4 15.8)	7.8 (6.2 9.3)	28.2 (24.7 33.2)	43.8 (37.1 51.4)	93.3 (79.4 109.7)
2001	14.3 (12 16.7)	7.7 (6.2 9.2)	28.1 (24.5 33)	44.6 (37.7 52.4)	94.7 (80.5 111.3)
2002	15.1 (12.6 17.7)	7.7 (6.2 9.2)	27.9 (24.4 32.8)	45.2 (38.1 53.1)	95.9 (81.3 112.7)
2003	15.8 (13.1 18.6)	7.6 (6.2 9.1)	27.8 (24.3 32.7)	45.5 (38.3 53.6)	96.8 (82 114)
2004	16.6 (13.5 19.6)	7.6 (6.2 9.1)	27.7 (24.3 32.7)	45.7 (38.4 53.9)	97.6 (82.5 115.2)
2005	17.3 (13.8 20.7)	7.6 (6.2 9)	27.7 (24.3 32.6)	45.7 (38.4 54.1)	98.2 (82.7 116.5)
2006	17.9 (14.1 21.8)	7.5 (6.2 9)	27.7 (24.3 32.7)	45.6 (38.1 54.4)	98.7 (82.7 117.9)
2007	18.5 (14.3 23)	7.5 (6.2 9)	27.7 (24.3 32.7)	45.4 (37.7 54.6)	99.1 (82.5 119.3)
2008	19 (14.4 24.3)	7.5 (6.2 9)	27.8 (24.3 32.8)	45.2 (37.2 54.8)	99.5 (82.2 120.9)
2009	19.4 (14.5 25.8)	7.5 (6.2 9)	27.9 (24.3 32.9)	45 (36.7 54.9)	99.7 (81.8 122.6)
2010	19.8 (14.5 27.3)	7.5 (6.2 9)	27.9 (24.3 33)	44.8 (36.3 55.2)	100 (81.4 124.4)
2011	20.1 (14.5 28.8)	7.5 (6.2 9)	28 (24.3 33.1)	44.6 (36 55.4)	100.1 (81 126.3)
2012	20.3 (14.5 30.3)	7.5 (6.2 9)	28 (24.3 33.2)	44.4 (35.8 55.6)	100.3 (80.7 128.1)

The status of British harbour seal populations in 2012

Callan D. Duck, Chris D. Morris and Dave Thompson.

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

Abstract

In August 2012, the Sea Mammal Research Unit (SMRU) surveyed part of Orkney, the wider Moray Firth and the Firth of Tay in Scotland; the survey of the Republic of Ireland, started in August 2011, was completed in September 2012; and in England, harbour seals were surveyed from fixed-wing aircraft in Lincolnshire, Norfolk and Suffolk. The Tees Seal Research Programme kindly provided information on seals in the Tees Estuary (Woods, 2012).

Since 2007, most groups of harbour and grey seals were photographed using a hand-held digital camera to confirm numbers and species identity. From surveys carried out between 2007 and 2012, the minimum number of harbour seals counted in Scotland was 21,320 and in England 4,568 making a total count for Great Britain of 25,888 (Table 1). Including 948 harbour seals counted in Northern Ireland in 2011, the new UK harbour seal total count was 26,836.

The 2012 survey of Orkney could not be completed, primarily due to poor weather reducing the time available for survey. In the Moray Firth, the mean count of adults from four surveys during the breeding season was lower than in 2011 while the moult count was marginally higher. In the Firth of Tay, the 2012 moult count (88) was marginally higher than the 2011 all-time-low count (77).

Introduction

Most surveys of harbour seals are carried out during their annual moult, in August. At this time of their annual cycle, harbour seals tend to spend longer at haul-out sites and the greatest and most consistent numbers 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. Although harbour seals can occur all around the UK coast, they are not evenly distributed. Their main concentrations are in Shetland, Orkney, the Outer Hebrides, the west coast of Scotland and in east and south-east England, mainly around Lincolnshire and Norfolk (Figure 1).

Surveys of harbour seals around the Scottish coast are carried out on an approximately five-yearly cycle, with the exception of the Moray Firth and Firth of Tay which are surveyed annually. In 2006, significant declines in harbour seal numbers were found in Shetland and in Orkney and elsewhere on the UK North Sea coast (Lonergan et al. 2007). Between 2007 and 2009, we surveyed the entire Scottish coast and repeated some parts of Strathclyde and Orkney. In 2010, Orkney was resurveyed to determine whether previously observed declines continued and because only a partial survey was completed in 2009. A new round-Scotland survey started in 2011 and should be completed in 2015. A complete survey of Northern Ireland and the Republic of Ireland was carried out in 2011 and 2012.

In 2012, as since 2007, most groups of seals were photographed with a high-resolution digital camera to confirm species identity and numbers in groups. These images were used to determine the classification of seals within haul-out groups. The grey seal data from these images has been used to inform the models used to estimate the total grey seal population size (Lonergan et al. 2011, SCOS BP 10/4)

In England, the Lincolnshire and Norfolk coast holds over 90% of the English harbour seal population and is usually surveyed twice annually during the August moult. Since 2004, Natural England has funded additional breeding season surveys (in early July) of harbour seals in Lincolnshire and Norfolk, including The Wash. During the moult in 2010 and the breeding season in 2011 the Suffolk, Essex and Kent coasts were surveyed.

In August 2013, with additional funding from SNH, we propose to survey the east and north coasts of Scotland, Orkney and part of the north-west coast of Scotland. In England, the standard surveys of the Lincolnshire and Norfolk coasts will be completed.

Funding from Scottish Natural Heritage and Natural England

Scottish Natural Heritage (SNH) has provided funding for harbour seal surveys every survey year since 1996. Without this additional funding, we would not have detected the serious decline in numbers in Shetland and Orkney and elsewhere around Scotland. Natural England provide funding for the breeding season surveys in the Wash.

Methods

Seals hauling out on rocky or seaweed covered shores are well camouflaged and difficult to detect. Surveys of these coastlines are carried out by helicopter using a thermal-imaging camera. The thermal imager can detect groups of seals at distances of over 3km. This technique enables rapid, thorough and synoptic surveying of complex coastlines. In addition, digital images were obtained using a camera equipped with an image-stabilised zoom lens. Both harbour and grey seals were digitally photographed and the images used to classify group composition.

In April 2013, SMRU were successful in obtaining a substantial grant from NERC to replace the Barr & Stroud IR18 thermal imaging camera that has been used since 1988. While it was not possible to identify and acquire a suitable system before the August 2013 survey, the new system will be in operation by August 2014 and should significantly improve the quality and efficiency of survey.

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

To maximise the counts of seals on shore and to minimise the effects of environmental variables, surveys are restricted to within two hours before and two hours after the time of local low tides (derived from POLTIPS, National Oceanographic Centre, NERC) occurring between approximately 12:00hrs and 18:00hrs. Surveys are not carried out in persistent or moderate to heavy rain because seals will increasingly abandon their haul-out sites and return into the water and because the thermal imager cannot 'see' through rain.

Results and Discussion

1. Minimum population size estimate for harbour seals in Britain

The overall distribution of harbour seals around the British Isles from August surveys carried out between 2007 and 2012 is shown in Figure 1. For ease of viewing at this scale, counts have been aggregated by 10km squares.

Minimum population estimates for Scotland, based on August surveys carried out between 2007 and 2012, between 2000 and 2005 and in 1996 and 1997, are shown in Table 1 along with equivalent counts from England. The Table also includes numbers from both Northern Ireland and the Republic of Ireland from surveys in 2011 and 2003 respectively. Updated numbers for the Republic of Ireland from 2011 and 2012 will be available when published by the Department of the Arts, Heritage and Gaeltacht.

Mean values have been used for any areas where repeat counts were obtained (primarily The Wash, Donna Nook, Blakeney Point and Scroby Sands and the breeding season surveys of the Moray Firth).

The most recent minimum estimate of the number of harbour seals in Scotland is 21,320 from surveys carried out between 2007 and 2012 (Table 1). This is virtually the same as the 2011 total (20,291) but 26.0% lower than the previous 2000 to 2005 total of 28,812 (Table 1). The most recent minimum estimate for England is 4,568, which is 13% higher than the 2011 count. The 2012 count comprises 4,189 seals in Lincolnshire and Norfolk plus 436 seals in Northumberland, Cleveland, Essex and Kent 2011 and an estimated 20 seals from the south and west coasts. The 2011 count for Northern Ireland (948) was 25.2% lower than the previous complete 2002 count (1,267).

Including the 948 harbour seals counted in Northern Ireland in 2011, gives a UK total of **26,836.**

2. Harbour seals in Scotland

The proposed survey area for August 2012 comprised the east coast of Scotland, including the Moray Firth and the Firth of Tay, the north coast of Scotland and Orkney. However, survey time was severely restricted due to poor weather and only the Firth of Tay, part of the Moray Firth and part of Orkney were completed.

To avoid confusion in reporting numbers for parts of Orkney that were surveyed in different years, we revert to the last, recent, complete survey that was carried out in August 2010. A detailed report of the full 2012 survey will shortly be available from SNH's website (Duck & Morris 2013). The areas of Scotland surveyed in different years are shown in Figure 2; the most recently surveyed areas are in green while areas in red were last surveyed in 2007 and most urgently require updating.

The most up to date distribution of harbour seals in Scotland, from surveys between 2007 and 2011, is shown in Figure 3. Grey seals are also counted during these surveys and their distribution in Scotland, over the same time period, is in Figure 4.

The trends in counts of harbour seals in different Seal Management Areas in Scotland, from surveys carried out between 1988 and 2012 are shown in Figure 5. Harbour seal numbers from the most recent surveys and from two previous surveys (between 2000 and 2005 and in 1996 and 1997) are in Table 1.

2.1 Moray Firth

Aberdeen University's Lighthouse Field Station, in Cromarty, obtained detailed annual breeding and moulting season counts of harbour seals in the Inner Moray Firth from June and July and from August between 1988 and 2005. These ground-based counts for the inner Moray Firth, from Ardersier to Loch Fleet, are shown in Figure 6a (breeding) and 6b (moulting). SMRU's aerial survey counts for the same areas are included, together with counts from adjacent haul-out sites at Culbin, Findhorn and along the coast between Loch Fleet and Helmsdale (Table 2, Figure 7). The part of the Moray Firth surveyed by SMRU, together with the August (moult) counts of harbour and grey seals in 2012, is shown in Figure 8. The area enclosed by the black line is that covered by the University of Aberdeen surveys between 1988 and 2005. August counts of grey seals in the Moray Firth are in Table 3.

2.1.1 Moray Firth - moult

SMRU's August aerial surveys of harbour seals in the Moray Firth started in August 1992 and the counts are shown in Table 2 with the trends in different parts of the Moray Firth in Figure 7. This figure represents a combination of both thermal imaging and fixed-wing surveys of the area. In 2012, the inner Moray Firth (Ardersier to Loch Fleet) count was 677, virtually identical to the 2011 count of 674. Following years of decline, harbour seal numbers in the Moray Firth increased in 2009 and 2010 but dropped back in 2011 and 2012 (Figures 6 and 7; Table 2). The declines may, at least in part, have been due to a bounty system for seals which previously operated in the area (Thompson et al., 2007). A manuscript modeling the change in the Moray Firth harbour seal population has recently been accepted for publication (Matthiopoulos et al., accepted in Oecologia). Counts of grey seals from SMRU's August surveys of the Moray Firth are shown in Table 3.

Since 2010, numbers of harbour seals moulting and breeding in the Beauly Firth have declined considerably (see Table 2 for moult counts, black section in Figure 7). Possible causes of this decline have not been identified, although on 14 July 2012, two jet skis were photographed in the upper reaches of the Firth, off Spital Shore. Numbers of harbour seals at Culbin, between Findhorn and Nairn have increased since 2010 from a few seals to over 100 (Figure 8).

2.1.2 Moray Firth – breeding season

During the 2012 breeding season, SMRU completed four out of five aerial surveys of harbour seals in the Moray Firth between mid-June and mid-July. The second survey was not attempted due to persistent, heavy rain. The mean number of adults counted during these surveys, with standard errors, is shown in Figure 6a. The mean count of harbour seal adults breeding in the inner Moray Firth, between Ardersier and Loch Fleet, in 2012 was 610 , 10.4% lower than the mean count from 2011 (681). The 2012 mean count for the wider Moray Firth, between Findhorn and Helmsdale was 762, 4.4% lower than the 2011 mean count of 796.

2.2 Firth of Tay

The 2012 harbour seal moult count for the Firth of Tay (88) was 12.5% higher than the 2011 all-time low count of 77 (Table 4). The 2012 count for this harbour seal SAC represented 13.7% of the mean of counts between 1990 and 2002 (641; Table 4, Figure 9). Harbour seals in the Firth of Tay are of sufficient concern that Marine Scotland did not issue any licences to shoot harbour seals within the East Scotland Management Area.

The area surveyed in the Firth of Tay is shown in Figure 10 with the distribution and numbers of harbour and grey seals counted during the 2012 survey (Figure 10a) compared with the numbers counted in the August 2000 survey (Figure 10b).

The numbers of grey seals counted in the Firth of Tay during harbour seal moult surveys are in Table 5.

3. Harbour seal surveys in England:

3.1. Moult season

In 1988, the numbers of harbour seals in The Wash declined by approximately 50% as a result of the phocine distemper virus (PDV) epidemic. Prior to this, numbers had been increasing. Following the epidemic, from 1989, the area has been surveyed once or twice annually in the first half of August each year (Table 6, Figure 11).

Two aerial surveys of harbour seals were carried out in Lincolnshire and Norfolk during August 2012 (Tables 1 and 6). In The Wash, the higher count in 2012 (3519) was 22% higher than the 2011 count (2894).

Overall, the combined count for the English east coast population (Donna Nook to Scroby Sands) in 2012 was 22% higher than the 2011 (Figure 8, Table 4). The English population has now returned to its pre 2002 epidemic levels but is still lagging behind the rapid recovery of the Wadden Sea population that has been increasing consistently since 2002 and increased by 12% p.a. between 2008 and 2012.

Harbour seals in the Tees Estuary are monitored by the Industry Nature Conservation Association (INCA). There appears to be a very slow recovery with numbers in August between 40 and 60 (mean count of 57 in August 2011; Woods 2008; Woods 2009; Woods 2010; Woods 2011). Low but increasing numbers of pups are born (16 were born in 2011with 12 surviving to weaning).

3.2. Breeding season

A survey conducted around the expected peak date (1/07/2012) produced counts of 1,469 pups and 3,551 older seals (1+ age classes) in The Wash during the 2012 breeding season compared with 1,106 pups and 3,283 older seals in 2011 and 1,432pups and 3,702 older seals in 2010. Pups were widely distributed, being present at most occupied sites in 2012 (SCOS BP 0x/13). The 2012 pup and adult counts were 33% and 8% higher respectively than the 2011 counts, and similar to those from 2010. Estimated peak pup counts have increased at an average rate of 9% p.a. since 2003 although there is considerable variation about the fitted exponential (R2=0.8).

4. Harbour seal surveys for 2013.

4.1 Breeding season

Four breeding season fixed-wing surveys were carried out in the Moray Firth in June and July 2013. The second survey was not attempted due to persistent heavy rain on the possible survey days.

A single survey was carried out on 29th June 2013 between Donna Nook and Scroby Sands in Suffolk.

4.2 Moult - 2013 surveys

In Scotland in 2013, the Scottish east coast, Orkney, the north coast and the northern part of the west coast of Scotland will be surveyed, weather and equipment permitting. The same methods will be used as in previous years, reviewing counts from digital still images. In April 2013, SMRU were awarded a NERC Capital Bids grant to purchase a new thermal imaging camera. It was not possible to acquire a suitable system in time for the 2013 survey but it will be available for use in 2014.

In England we intend to carry out two surveys of the coast between Donna Nook and Scroby Sands. In addition, ZSL intend to carry out two surveys of the Essex and Kent coasts.

Acknowledgements

We are grateful to NERC, all the Countryside Agencies and the Department of the Arts, Heritage and Gaeltacht of Ireland for providing the funding to carry out surveys of seals in their respective areas. SNH has provided very significant funding for Scottish surveys since 1996; Natural England funded recent surveys of The Wash and surrounding coasts. The Irish surveys were funded by the Northern Ireland Environment Agency (previously the Environment and Heritage Service) and the National Parks and Wildlife Service of the Department of the Arts, Heritage and Gaeltacht for Northern Ireland and Ireland respectively. Very special thanks to Oliver O'Cadhla and Eamonn Kelly for help with the surveys of Ireland in August 2011 and 2012.

We are also extremely grateful for, and utterly dependent on, the technical expertise so enthusiastically provided by the companies supplying the survey pilots and aircraft: PDG Helicopters, Giles Aviation, Highland Aviation and Caledonian Air Surveys Ltd.

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Table 1. Minimum estimates of the UK harbour seal population in Management Areas from the most recent and from two previous surveys. These are the numbers of seals counted in aerial surveys with the survey year below the number of seals counted. A new figure for the Republic of Ireland will be available shortly.

Harbour seal Management Area	Most recent count (2007-2012)	2000-2005 count	1996-1997 count
Shetland (including Foula from 2006)	**3,039** 2009	**4,883** 2001	**5,991** 1997
Orkney	**2,687** 2010	**7,752** 2001	**8,523** 1997
North Coast (Duncansby Head to Cape Wrath)	**112** 2008	**174** 2005	**265** 1997
Outer Hebrides	**2,739** 2011	**2,067** 2003	**2,820** 1996
West Scotland – North & Central (Cape Wrath to Ardnamurchan Point)	**4,696** 2007, 2008	**4,665** 2005	**3,160** 1996, 1997
West Scotland - South (Ardnamurchan Point to Mull of Kintyre)	**5,915** 2007, 2009	**7,003** 2000, 2005	**5,651** 1996
South-west Scotland, Firth of Clyde (Mull of Kintyre to Loch Ryan)	**811** 2007	**581** 2005	**923** 1996
South-west Scotland, Dumfries & Galloway (Loch Ryan to English Border by Carlisle)	**23** 2007	**42** 2005	**6** 1996
East Scotland, Firth of Forth (English Border to Fife Ness)	**148** 2007	**280** 2005	**116** 1997
East Scotland, east coast (Fife Ness to Fraserburgh)	**178** 2007, 2012	**406** 2005	**648** 1997
Moray Firth (Fraserburgh to Duncansby Head)	**972** 2007, 11, 12	**959** 2005	**1429** 1997
TOTAL SCOTLAND	**21,320**	**28,812**	**29,532**
North-east England (Border to Flamborough Head)	**70** 2007, 2012	**52** 1994, 2005	**47** 1994, 1997
South-east England: (Flamborough Head to Newhaven)	(2012)	(2005)	(1997)
Donna Nook	**192**	**421**	**251**
The Wash	**3,372**	**1,946**	**2,461**
Blakeney Point	**409**	**709**	**311**
Scroby Sands	**216**	**57** 2004	**65**
Suffolk, Essex & Kent	**379** 2010	**101** 1994-2003	**90** 1994 –1997
West England & Wales (estimated)	**20**	**20**	**15**

TOTAL ENGLAND	**4,658**	**3,306**	**3,240**
TOTAL BRITAIN	**25,888**	**32,118**	**32,772**
TOTAL NORTHERN IRELAND	**948** 2011	**1,267** 2002	
TOTAL BRITAIN & N. IRELAND	**26,836**	**33,385**	
TOTAL REPUBLIC OF IRELAND	**2,955** 2003	**2,955** 2003	
TOTAL GREAT BRITAIN & IRELAND	**29,791**	**36,340**	

Table 2. Counts of harbour seals in the Moray Firth. Mean value if there was more than one count in any year; red = lowest count, green = highest count. The distribution of harbour seals in the Moray Firth in 2012 is shown in Figure 8 and a histogram of these data is in Figure 7. Data are from aerial surveys by the Sea Mammal Research Unit. Since 2006, all surveys incorporated hand-held oblique digital photography.

fw = fixed-wing aircraft; ti = helicopter thermal image survey.

Location	**Aug 1992**	**end July 1993**	**Aug 1994**	**Aug 1997**	**Aug 2000**	Aug 2002*	**Aug 2003**	**Aug 2004**	**Aug 2005**	**Aug 2006**	**Aug 2007**	**Aug 2008**	**Aug 2009**	**Aug 2010**	**Aug 2011**	**Aug 2012**
Survey Method(n)	fw	fw	fw	ti	fw	fw ti	fw	2 fw	2 fw 1 ti	ti fw	ti	ti fw	fw	fw	ti	fw
Ardersier	154		221	234	191	110	205	202	206	197	154	145	277	362	195	183
Beauly Firth	220		203	219	204	66	151	178	127	176	146	150	85	140	57	60
Cromarty Firth	41		95	95	38	42	113	88	106	106	102	90	90	140	101	144
Dornoch Firth (SAC)	662		542	593	405	220	290	230	191	256	144	145	166	219	208	157
Inner Moray Firth Total	**1077**		**1061**	**1141**	**838**	**438**	**759**	**698**	**630**	**736**	**544**	**530**	**618**	**861**	**561**	**544**
Loch Fleet		*16*		*27*	*33*	*62*	*56*	*64*	*71*	*80*	*82*	*82*	*65*	*114*	*113*	*133*
IMF + L Fleet		**1093**	**1077**	**1168**	**871**	**500**	**815**	**762**	**701**	**815**	**627**	**612**	**683**	**975**	**674**	**677**
Findhorn & Culbin			*58*	*46*	*111*	*144*	*167*	*49*	*92*	*58*	*79*	*92*	*73*	*123*	*163*	*254*
IMF + L Fleet + Findhorn + Culbin			**1135**	**1214**	**982**	**644**	**982**	**811**	**793**	**873**	**706**	**704**	**756**	**1098**	**837**	**931**
Brora + Helmsdale		*92*		*214*		*188*			*38*	*150*	*54*	*72*	*19*	*101*	*87*	*102*
IMF+LF+FC+BH Total		**1185 ****	**1227 ****	**1428**		**832**			**831**	**1023**	**760**	**776**	**775**	**1199**	**924**	**1033**

*2002 count very late in tide and numbers may be lower than if closer to low tide.

**Note that the Total counts for 1993 and 1994 both include Loch Fleet data from 1993.

Table 3. Counts of grey seals in the Moray Firth. Mean value if there was more than one count in any year; red = lowest count, green = highest count per area. The distribution of grey seals in 2012 is shown in Figure 8. Data are from aerial surveys by the Sea Mammal Research Unit. Since 2006, all surveys were by hand-held oblique digital photography.

fw = fixed-wing aircraft; ti = helicopter thermal image survey.

Location	Aug 1992	end July 1993	Aug 1994	Aug 1997	Aug 2000	Aug 2002	Aug 2003	Aug 2004	Aug 2006	Aug 2007	Aug 2008	Aug 2009	Aug 2010	Aug 2011	Aug 2012
Survey Method	fw	fw	fw	ti	fw	fw ti	fw	2 fw	fw ti	ti	ti fw	fw	fw	ti	fw
Ardersier	0		36	24	85	0	0	62	138	74	117	94	297	74	24
Beauly Firth	8		2	3	8	0	0	2	3	4	0	0	2	3	1
Cromarty Firth	9		0	0	0	0	0	0	1	0	0	0	1	2	1
Dornoch Firth (SAC)	233		903	456	121	321	79	569	748	516	569	819	717	679	74
Inner Moray Firth Total (IMF)	**250**		**941**	**483**	**214**	**321**	**79**	**631**	**890**	**594**	**686**	**913**	**1017**	**758**	**100**
Loch Fleet					*0*	*0*	*0*	*0*	*1*	*2*	*2*	*0*	*7*	*7*	*20*
IMF + L Fleet					**214**	**321**	**79**	**631**	**891**	**596**	**688**	**913**	**1024**	**765**	**120**
Findhorn & Culbin					*0*	*0*	*10*	*20*	*10*	*28*	*67*	*58*	*58*	*179*	*121*
IMF + L Fleet + Findhorn + Culbin						**321**	**89**	**651**	**902**	**624**	**754**	**971**	**1082**	**944**	**241**
Brora + Helmsdale				*3*		*6*			*102*	*52*	*499*	*72*	*635*	*160*	*316*
IMF+LF+FC+BH Total						**327**			**1003**	**676**	**1254**	**1043**	**1717**	**1104**	**557**

*2002 count very late in tide and numbers may be lower than if closer to low tide.

Table 4. Counts of harbour seals in the Firth of Tay and Eden Estuary harbour seal SAC (see Figure 10 for 2012 seal distribution data); highest counts in green, lowest in red. Data are from aerial surveys by the Sea Mammal Research Unit. Since 2006, all surveys incorporated hand-held oblique digital photography. A histogram of these data is shown in Figure 9.

fw = fixed-wing aircraft; ti = helicopter thermal image survey.

Location	Aug 1990	Aug 1991	Aug 1992	Aug 1994	Aug 1997	Aug 2000	Aug 2002	Aug 2003	Aug 2004	Aug 2005	Aug 2006	Aug 2007	Aug 2008	Aug 2009	Aug 2010	Aug 2011	Aug 2012
Survey Method	fw	fw	fw	fw	ti	fw	fw	fw	fw	fw, ti	fw	ti	fw	fw	fw	fw	fw
Eden Estuary	31	0	0	80	223	267	341	93	78	105	90	89	83	22	36	32	19
Abertay & Tentsmuir	409	428	456	289	262	153	167	53	126	63	34	31	50	8	9	0	5
Upper Tay	27	73	148	89	113	115	51	83	134	91	91	63	49	45	41	16	40
Broughty Ferry		83	97	64	35	52		90	55	51	127	24	13	28	15	18	16
Buddon Ness		86	72	53	0	113	109	142	66	25	0	67	27	8	23	11	8
Firth of Tay Total (SAC)	**467**	**670**	**773**	**575**	**633**	**700**	**668**	**461***	**459**	**335**	**342**	**274**	**222**	**111**	**124**	**77**	**88**

*In August 2003 low cloud prevented the use of vertical photography; counts were from oblique photographs and from direct counts of small groups of seals.

Table 5. Counts of grey seals in the Firth of Tay harbour seal SAC (see Figure 10 for 2012 data); highest counts in green, lowest in red. Data are from aerial surveys by the Sea Mammal Research Unit.

fw = fixed-wing aircraft; ti = helicopter thermal image survey.

Location	Aug 1990	Aug 1991	Aug 1992	Aug 1994	Aug 1997	Aug 2000	Aug 2002	Aug 2003	Aug 2004	Aug 2005	Aug 2006	Aug 2007	Aug 2008	Aug 2009	Aug 2010	Aug 2011	Aug 2012
Survey Method	fw	fw	fw	fw	ti	fw	fw	fw	fw	fw, ti	fw	ti	fw	fw	fw	fw	fw
Eden Estuary	0	0	16	0	10	0	25	4		27.3	57	14	33	0	39	17	36
Abertay & Tentsmuir	912	1546	1191	1335	1820	2088	1490	1560		763	1267	1437	483	400	1406	1265	1111
Upper Tay	0	0	18	20	61	64	78	50		42	22	29	26	55	98	16	32
Broughty Ferry	0	3	0	9	0	0	0	0		0	8	1	8	0	0	2	3
Buddon Ness	0	0	1	104	0	101	0	49		11	25	78	7	0	12	22	13
Firth of Tay Total (SAC)	**912**	**1549**	**1226**	**1468**	**1891**	**2253**	**1593**	**1614**		**843**	**1379**	**1559**	**557**	**455**	**1555**	**1322**	**1195**

Table 6. Number of harbour seals counted on the east coast of England since 1988; see Figure 10. Data are from fixed-wing aerial surveys carried out by the Sea Mammal Research Unit during the August moult. Data from the Tees Estuary were provided by Robert Woods, with the exception of an aerial count by SMRU in 1994. Grey cells = no survey.

	North-east England		South-east England				
Year	**Holy Island [1], N'umberland**	**The Tees [2]**	**Donna Nook**	**The Wash (SAC)**	**Blakeney Point**	**Scroby Sands**	**Essex, Suffolk & Kent**
1988			173	3,087	701		
1989		16	126	1,556 *	307		
1990		22	57	1,532	73		
1991		22		1,389 *			
1992		28	18	1,671 *	217		
1993		30	88	1,759	267		
1994	13	35	103 *	2,011 *	196	61	
1995		32	76 *	2,084 *	415 *	49	
1996		42	162	2,151	372	51	
1997	12	42	251 *	2,461 *	311 *	65 *	
1998		41	248 *	2,381	637 *	52	
1999		35	304 *	2,397 *	659 *	72 *	
2000	10	58	390 *	2,779 *	895 *	47 *	
2001		59	233	3,194	772	75	
2002		52	341	2,977 *	489 *		72
2003		38	231	2,513 *	399		180
2004		40	294 *	2,147 *	646 *	57 *	
2005	17	50	421 *	1,946 *	709 *		
2006		45	299	1,695	719	71	
2007	7	43	214	2,162	550		
2008		41	191 *	2,010 *	581 *	81 *	319
2009		49	267 *	2,829 *	372	165 *	
2010		53	176 *	2,539 *	391	201 *	379
2011		57	205	2,894	349	119	
2012		63	192	3,372 *	409	216	

[1] Holy Island surveyed by fixed-wing in 1994 & 2000, otherwise using a helicopter and thermal imaging camera.

[2] Tees data 1989-2012 kindly provided by Robert Woods, INCA (Woods 2012). SMRU aerial survey in 1994.

* Mean total from two complete August surveys.

Figure 1. The distribution of harbour seals around Great Britain and Ireland, aggregated by 10km squares. Data for Scotland and England are for surveys carried out between 2007 and 2011, data from Ireland are from surveys in 2002 and 2003. Very small numbers of harbour seals are anecdotally but increasingly reported in south-west and west England and in Wales but are not included in this Figure.

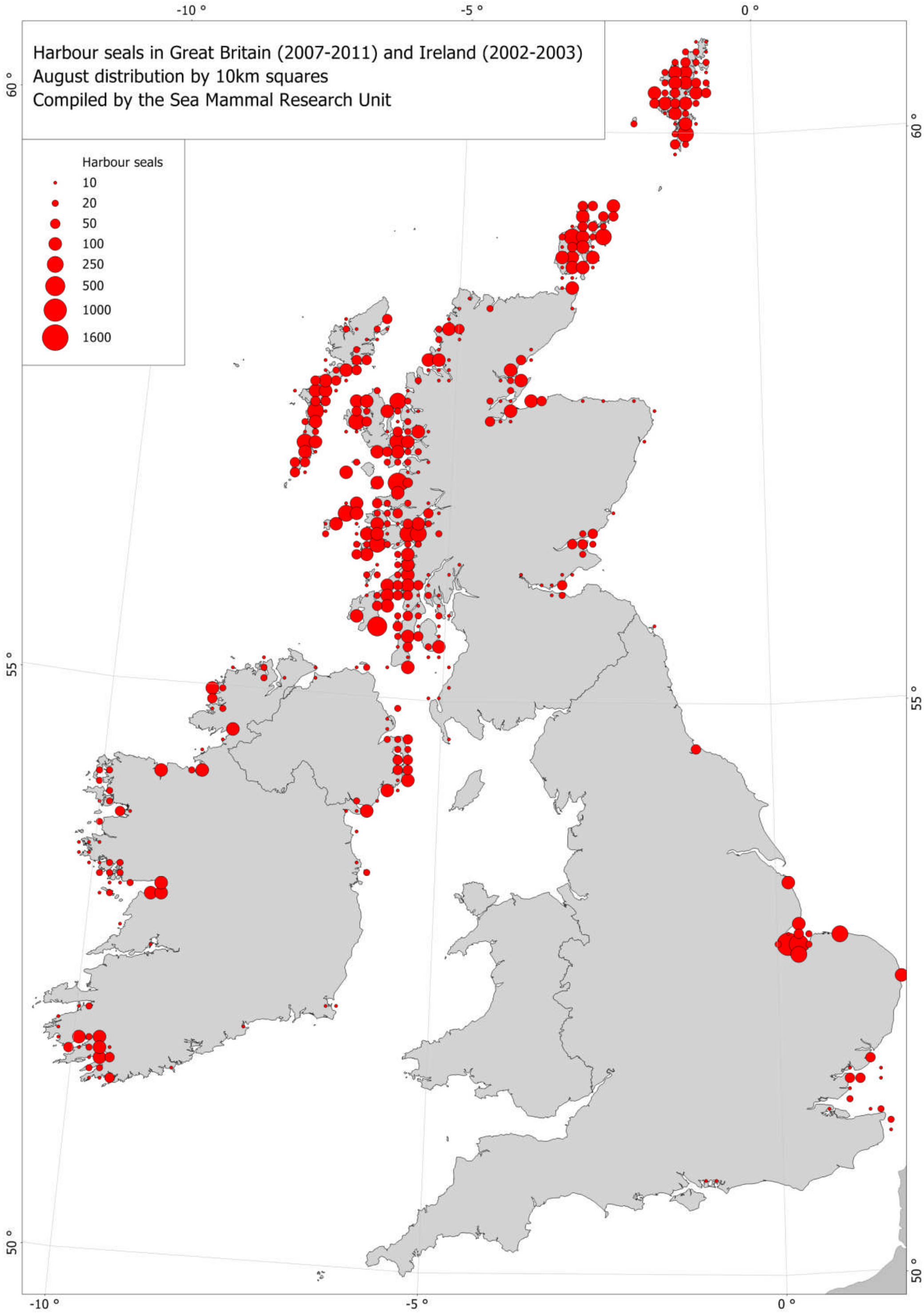


Figure 2. Map showing the years in which different parts of Scotland were surveyed for harbour seals most recently by helicopter using a thermal imaging camera. Most areas were surveyed between 2007 and 2011. Foula, off Shetland, was last surveyed in 2006. The enclosed areas of the Firth of Tay and the Moray Firth (between Findhorn and Helmsdale) are surveyed every year, usually by fixed-wing aircraft.

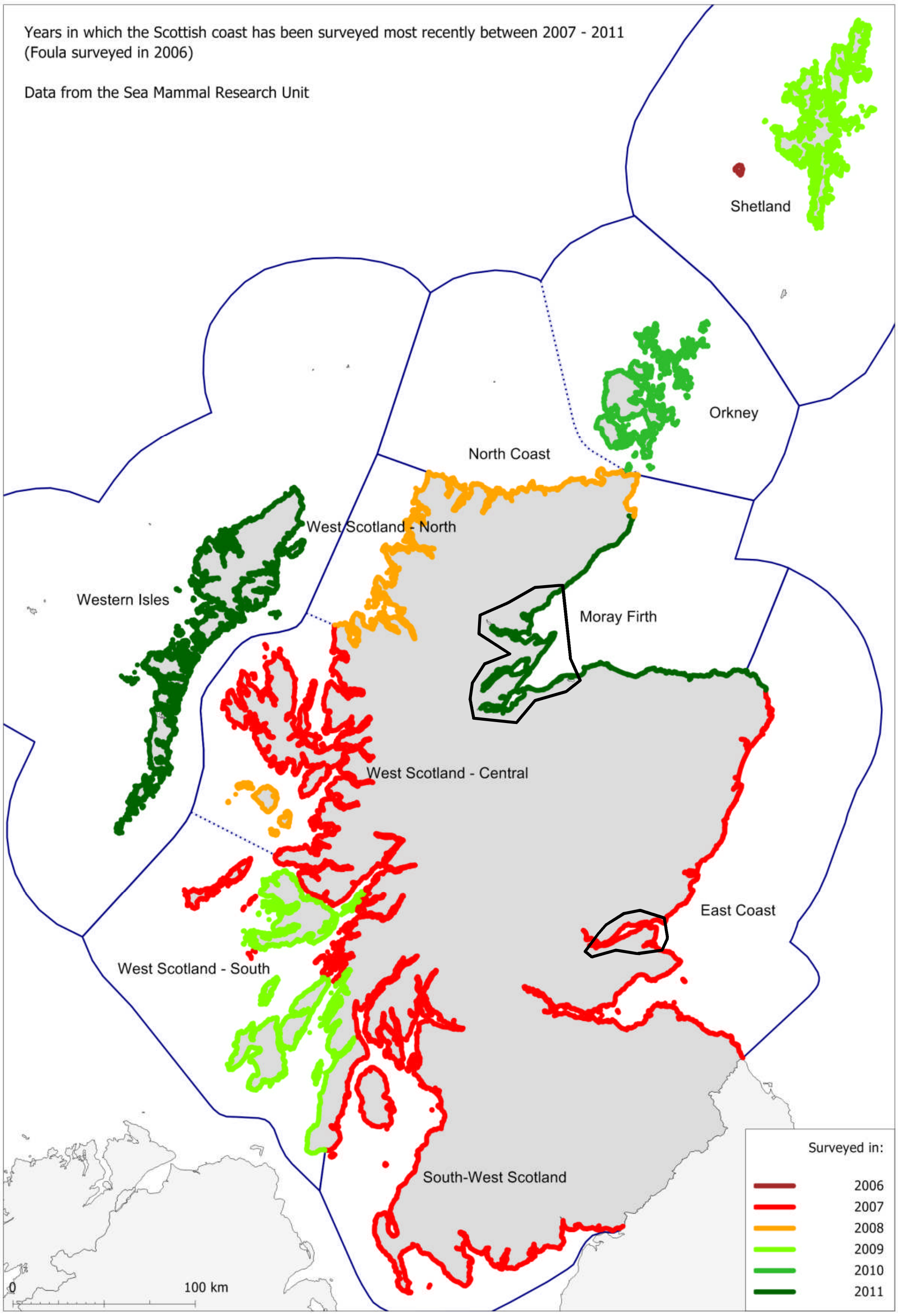


Figure 3. The number and distribution of harbour seals in Management Areas around the coast of Scotland, from surveys carried out between August 2007 and 2011. All areas were surveyed by helicopter using a thermal imaging camera.

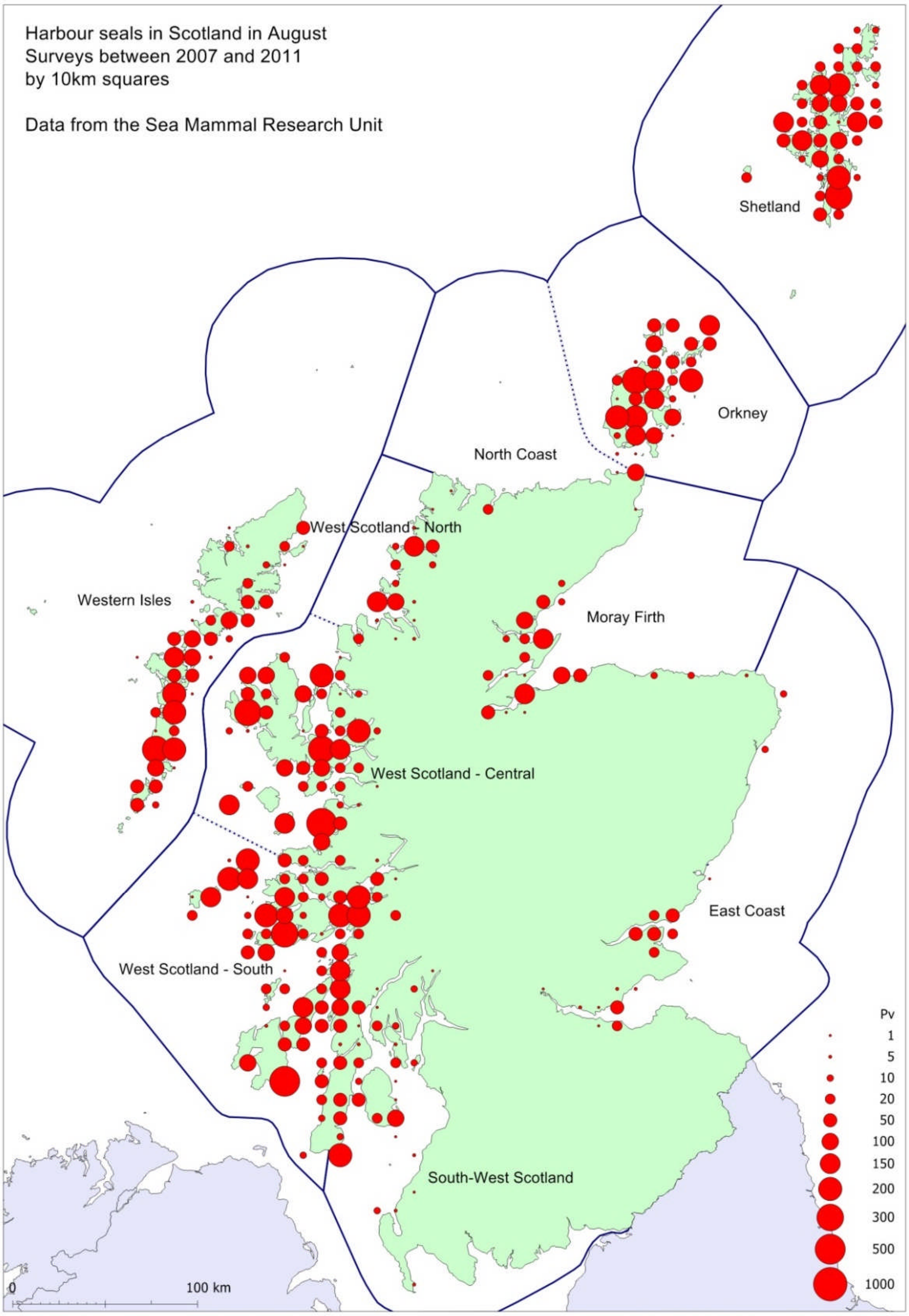


Figure 4. The number and distribution of grey seals in Management Areas around the coast of Scotland, from surveys carried out between August 2007 and 2011. All areas were surveyed by helicopter using a thermal imaging camera.

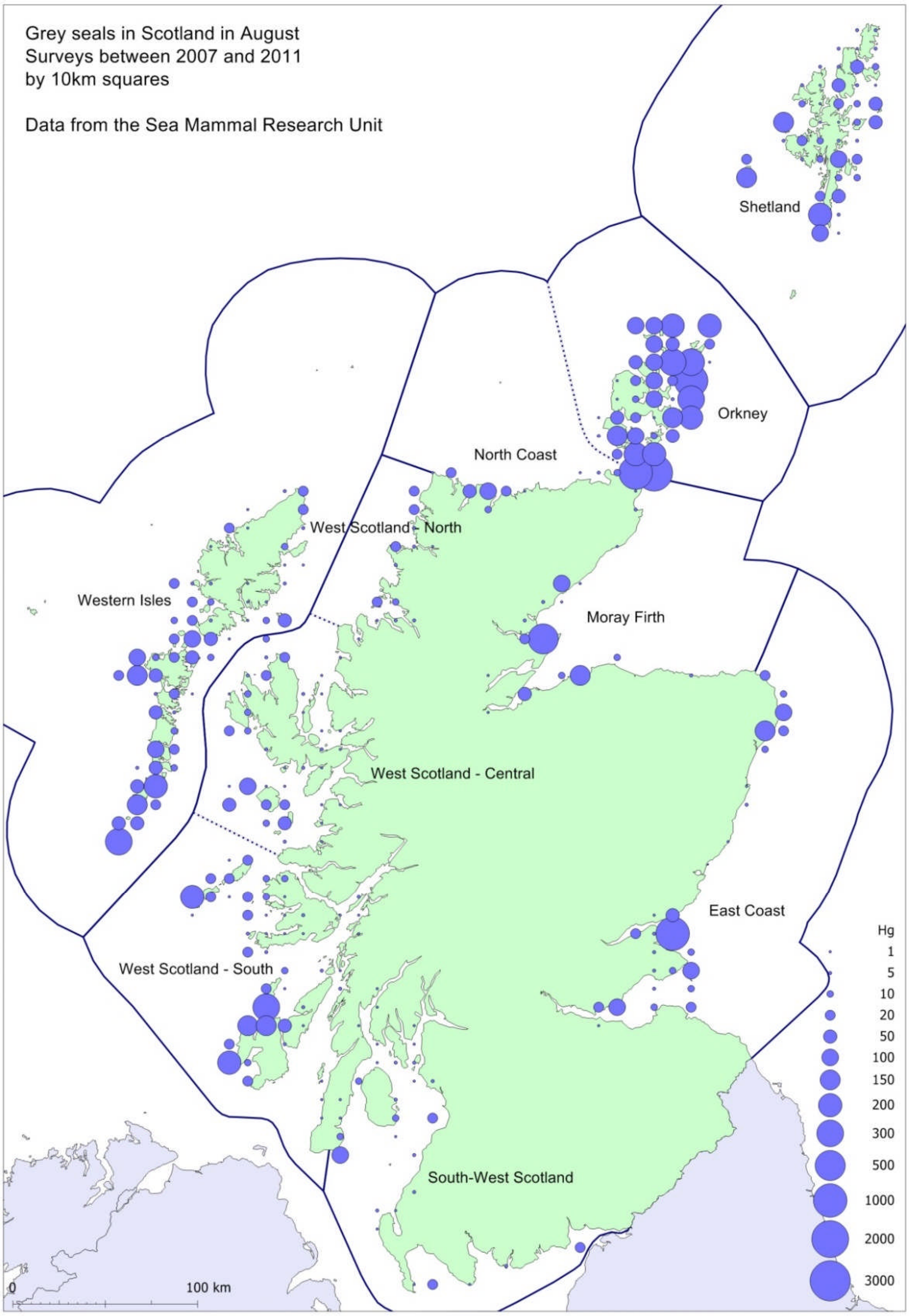


Figure 5. Counts of harbour seals in Management Areas in Scotland. Data from the Sea Mammal Research Unit

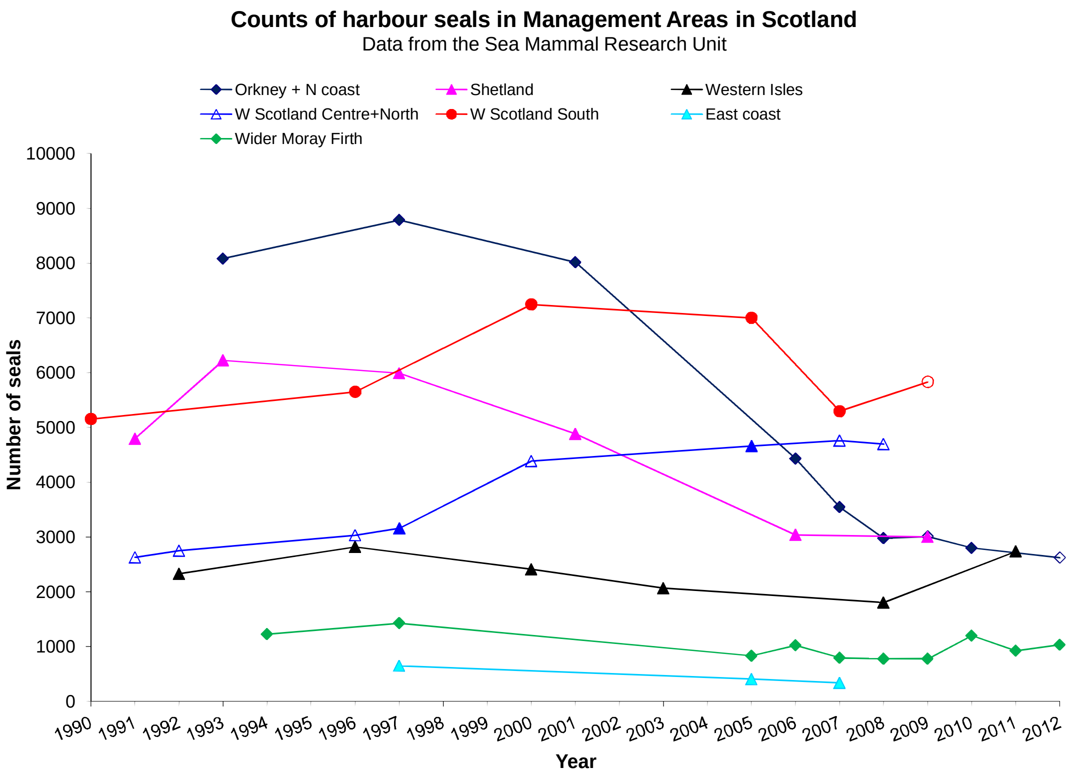


Figure 6a. Counts of harbour seals in the Moray Firth during the breeding season. Mean counts with standard errors.

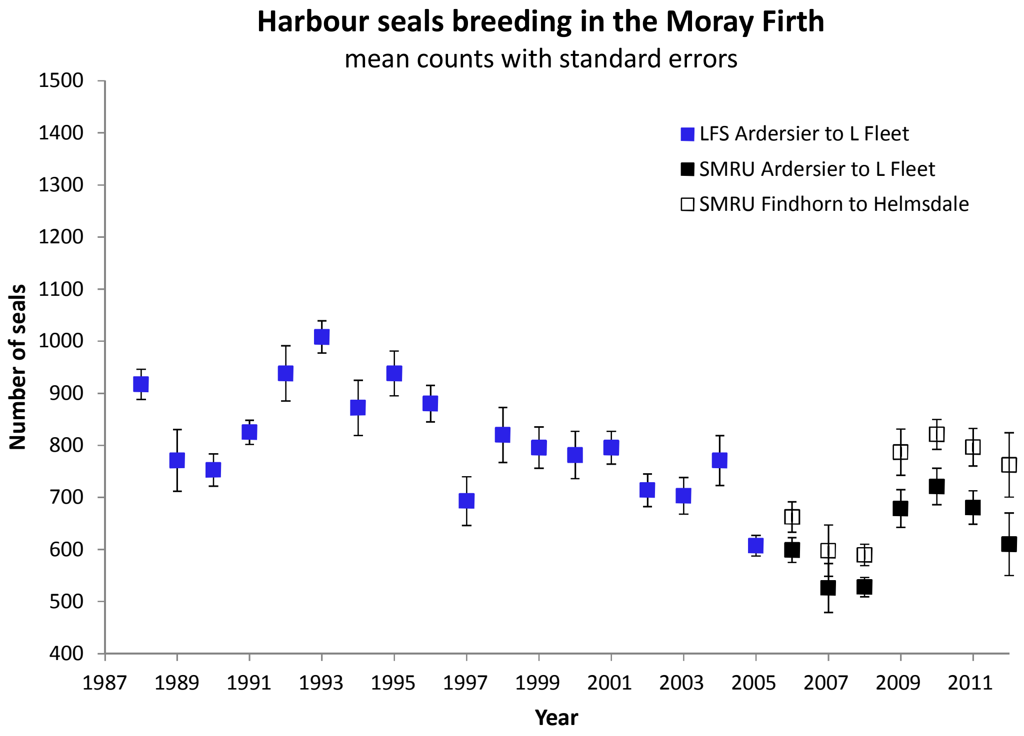


Figure 6b. Counts of harbour seals in the Moray Firth during the August moult. Mean counts with standard errors where available. Details from moult surveys by the Sea Mammal Research Unit are in Figure 7.

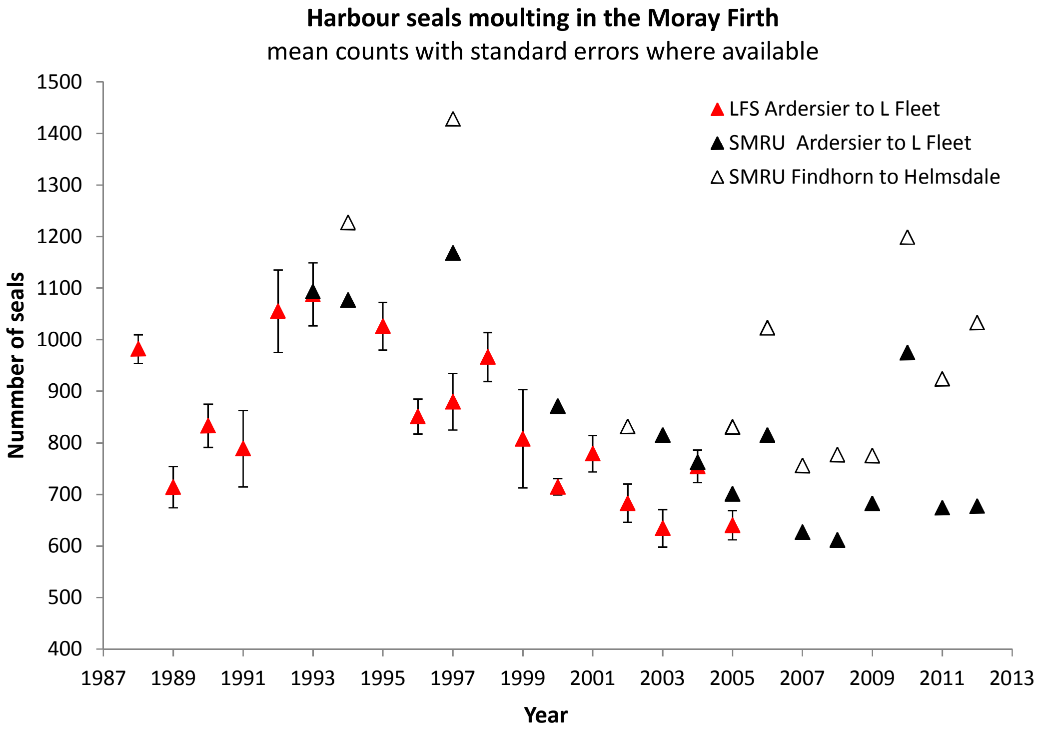


Figure 7. August counts of harbour seals in different areas of the Moray Firth. The black line represents the total count for all areas between Ardersier and Loch Fleet.

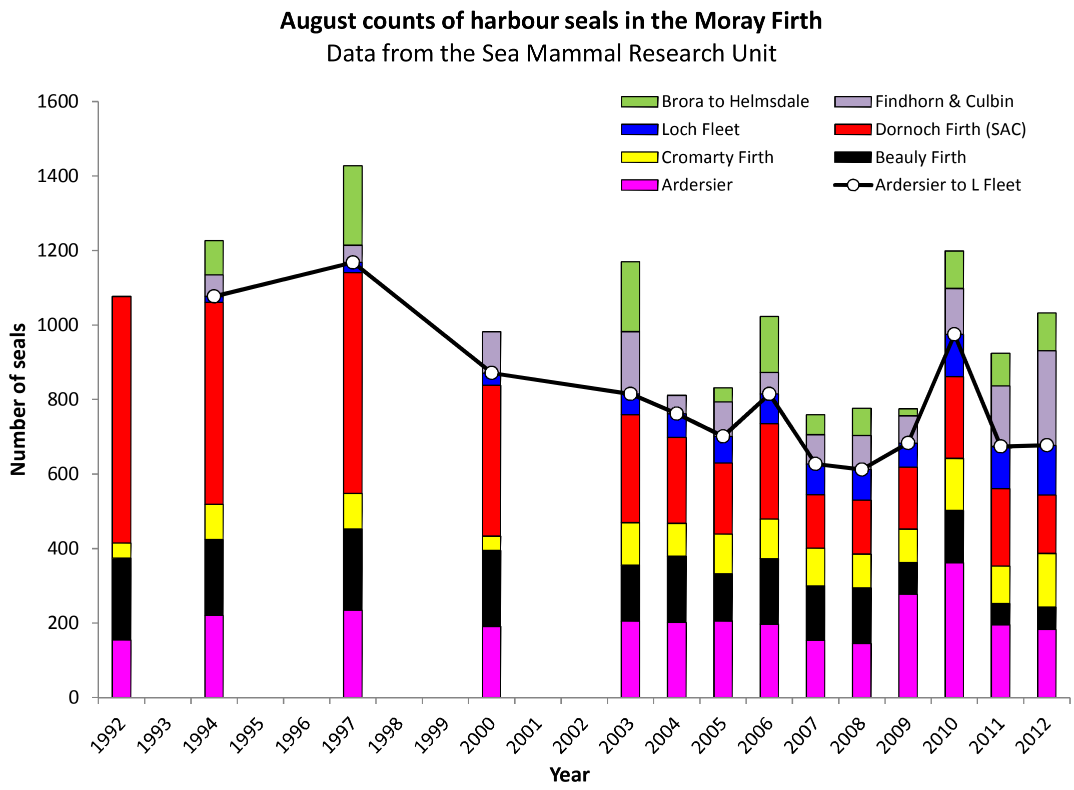


Figure 8. Harbour and grey seals counted in the wider Moray Firth, between Findhorn and Helmsdale from an aerial survey carried out on 9th August 2012. The areas listed in Tables 5 and 6 and also used in Figure 7 are shaded in blue. Data are from the Sea Mammal Research Unit.

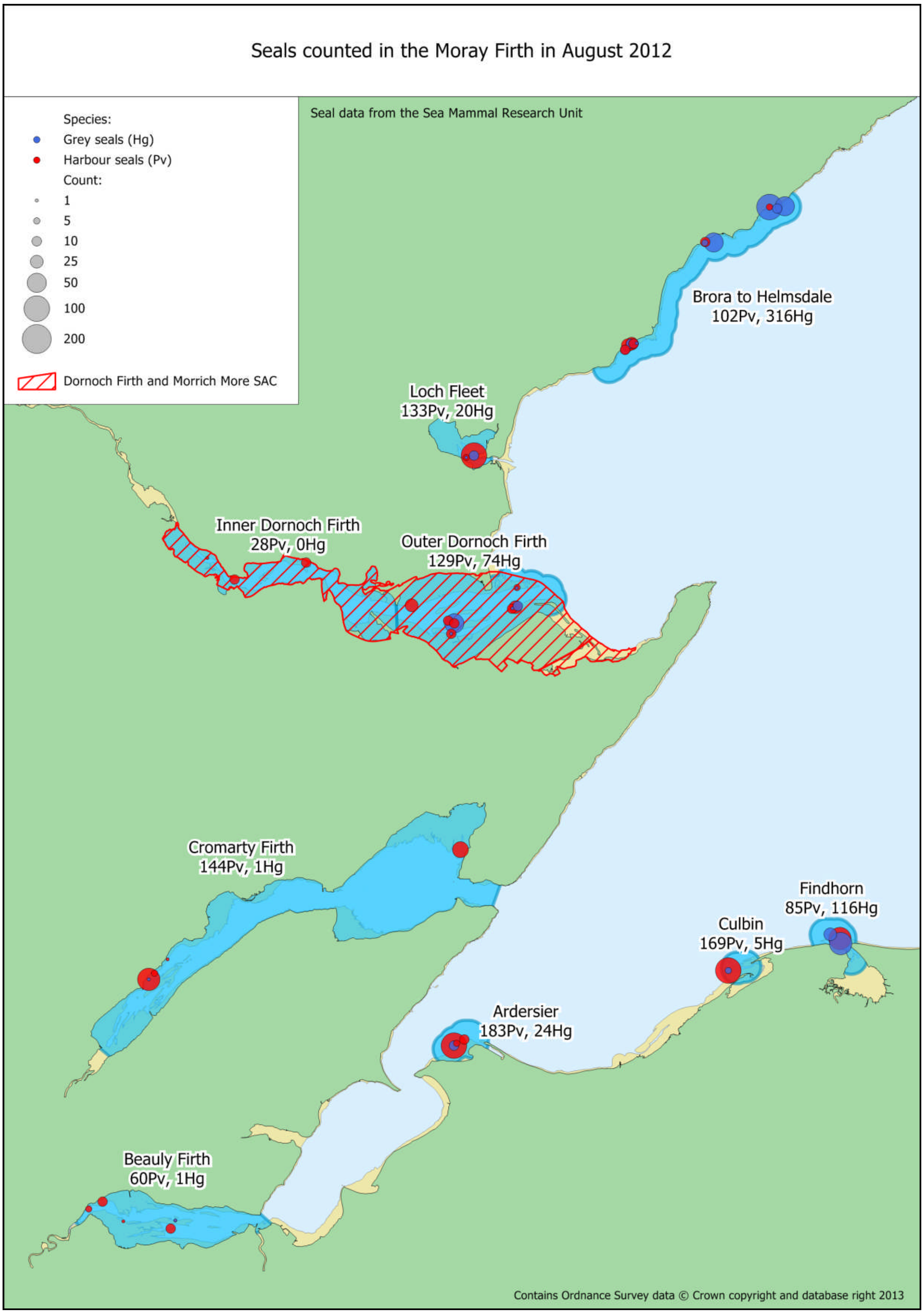


Figure 9. August counts of harbour seals in the Firth of Tay. Horizontal lines are the mean counts for the three time periods. A comparison of the distribution of harbour and grey seals in Firth of Tay in August 2012 and August 2000 is shown in Figure 10.

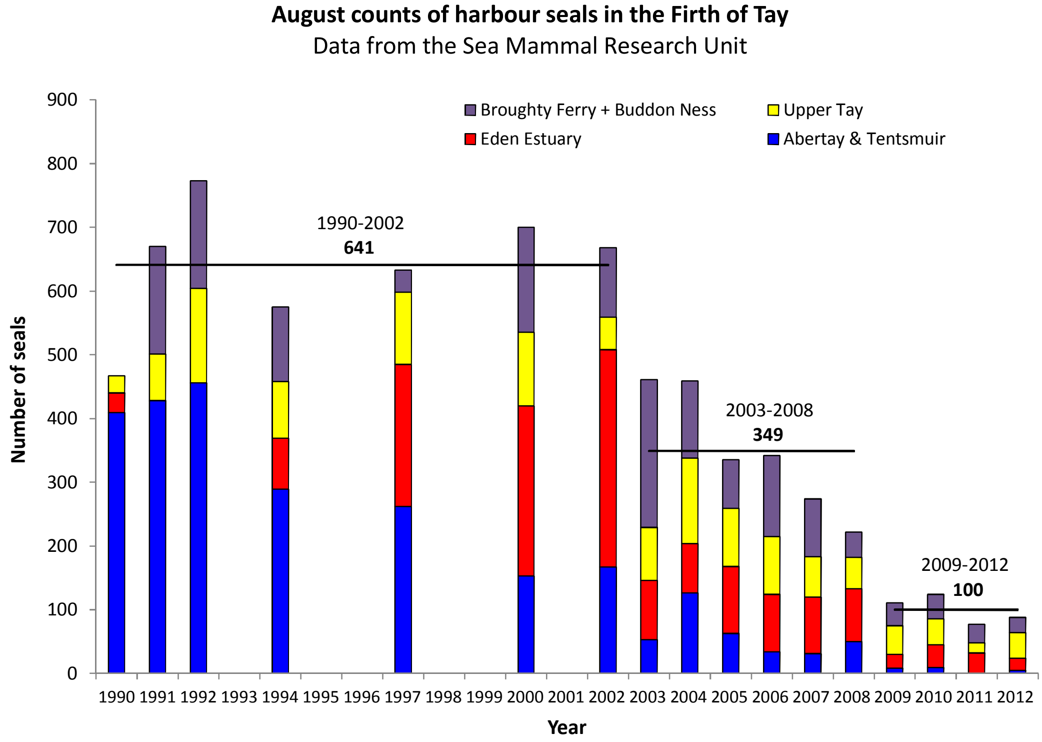
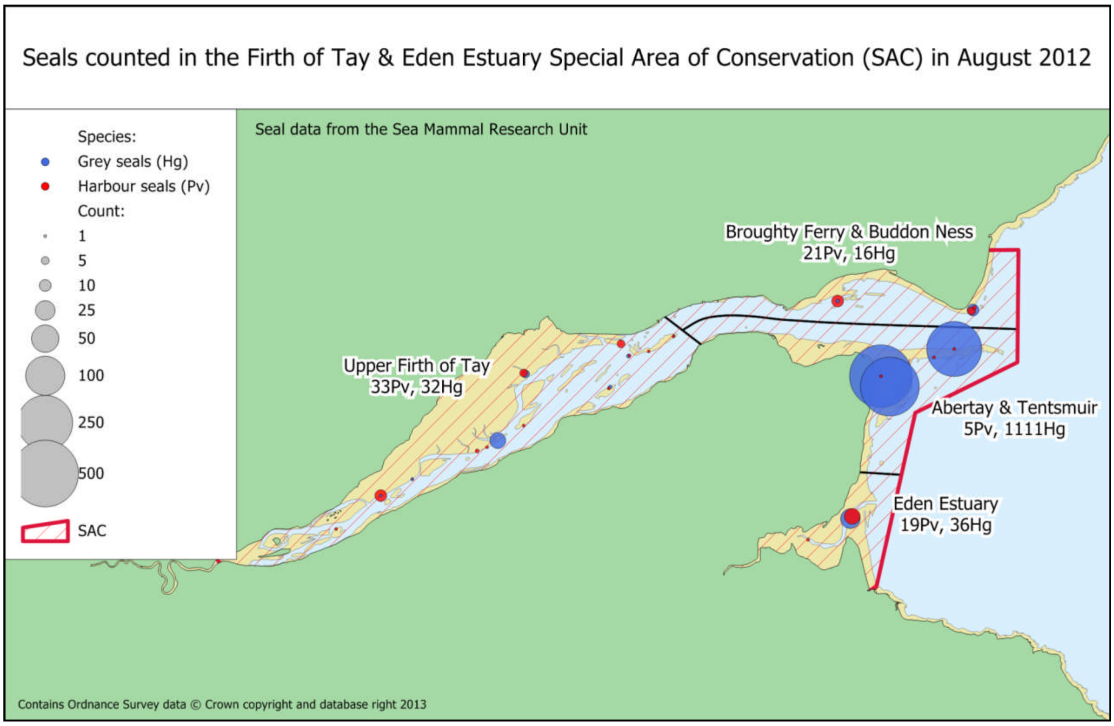


Figure 10. Harbour and grey seals in the Firth of Tay showing the differences between 1st August 2012 (a) and
12th August 2000 (b). Data are from the Sea Mammal Research Unit.

(a)



(b)

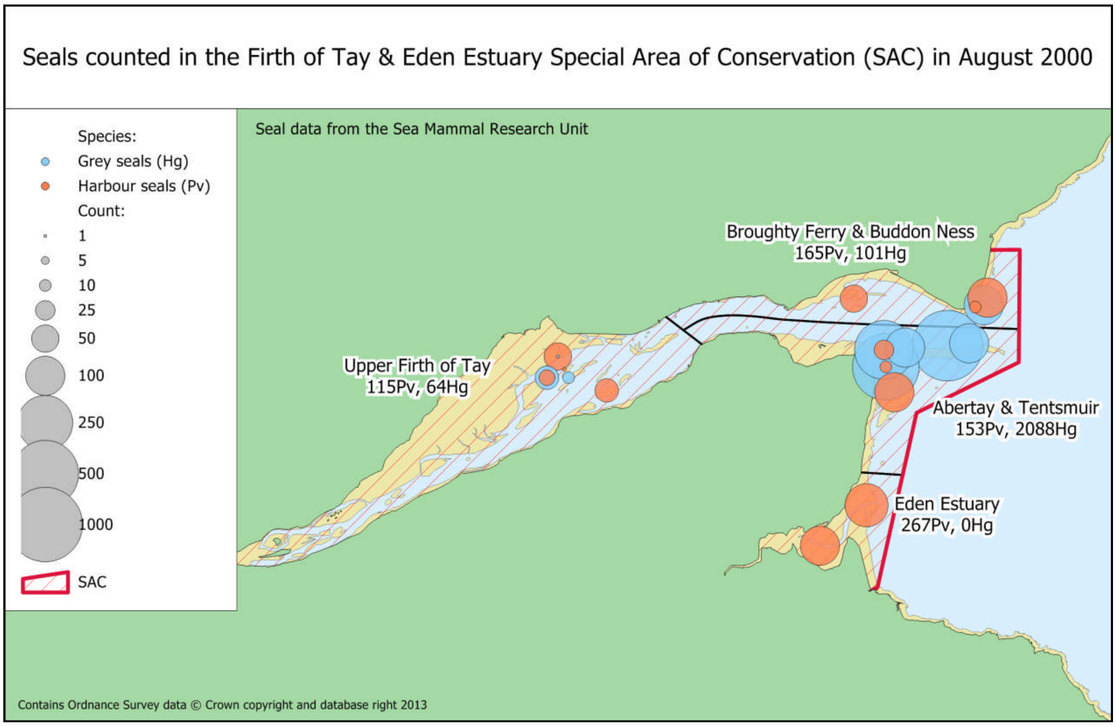
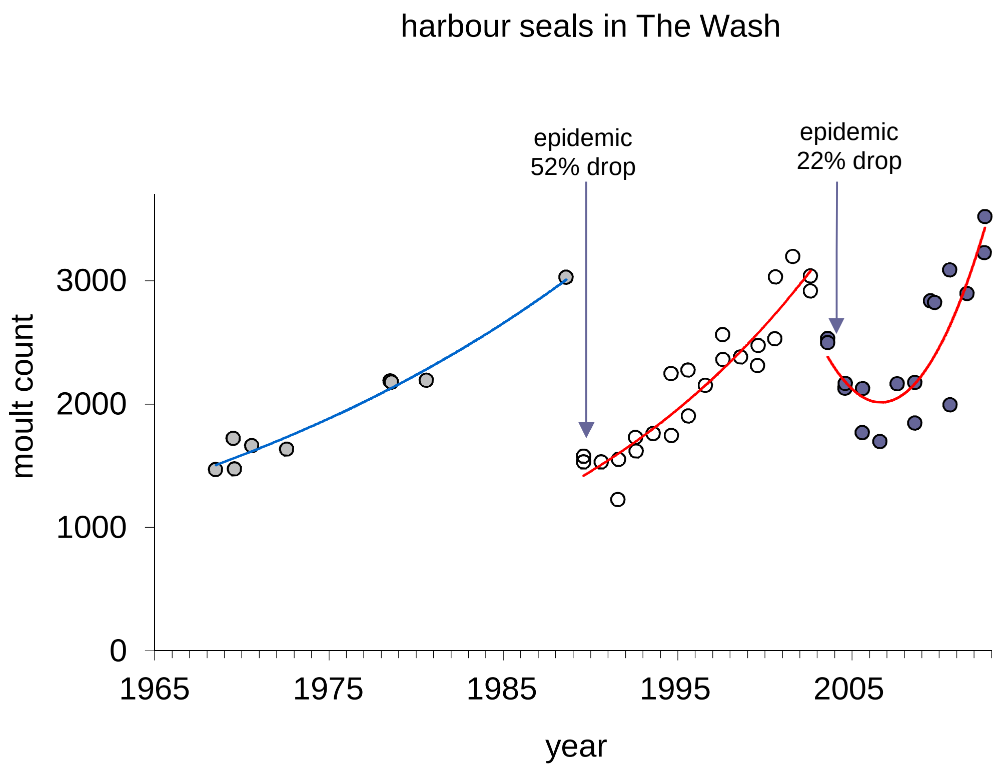


Figure 11. Counts of moulting harbour seals in The Wash, 1967-2012.



Trends in harbour seal (*Phoca vitulina*) pup counts in The Wash.

Dave Thompson, Luke Connor and Mike Lonergan

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

Abstract

This report presents the results of breeding season aerial surveys of the harbour seal population in The Wash on the English east coast. The primary aim of the study was to establish a monitoring programme to provide regular estimates of the pup production of the harbour seal population in the Wash SAC. These data can be used in conjunction with a regular, annual, NERC funded population monitoring programme to provide a more sensitive indication of the current status of the population.

Results suggest that:

1. The 2012 count was the highest pup count ever obtained in the Wash
2. The pup production in the Wash has increased at around 9% p.a. since surveys began in 2001
3. The ratio of pups to total population has increased gradually over the period and the ratio was 2.7 times higher in 2012 than in 2001 suggesting a large increase in apparent fecundity
4. There appear to be large inter-annual fluctuations in apparent fecundity

Introduction

The Wash is the largest estuary in England, and holds the majority of the English harbour seal (*Phoca vitulina*) population (Vaughan, 1978). This population has been monitored since the 1960s, using counts of animals hauled out during the moult as indices of population size. The initial impetus for monitoring this population was to investigate the effects of intensive pup hunting. When this hunt ceased in 1973 the monitoring program was reduced.

As it is difficult to estimate absolute abundance, monitoring programmes have usually been directed towards obtaining indices of population size. Counts are usually carried out during the annual moult, when the highest and most stable numbers of seals haulout. Unfortunately such counts do not provide a sensitive index of current population status. It is generally accepted that breeding success is a more sensitive index. The breeding season is also the time when disturbance of seal haulout groups is likely to have direct effects. E.g. disturbance of mother/pup pairs will lead to temporary separation which may have direct effects on pup survival, especially if the disturbance is repeated.

Since 2004 Natural England have commissioned single annual breeding season surveys to develop a time series of pup counts as an adjunct to the annual moult surveys to obtain a more sensitive index of current status as well as to monitor the distribution of breeding seals.

Methods

Based on a preliminary assumption that the peak number of pups would be encountered at the end of June or beginning of July we have surveyed the breeding population between 27th June and 4th July in each year from 2004 to 2012. Surveys were carried out over the period 1.5 hours before to 2 hours after low water. All tidal sand banks and all creeks accessible to seals were examined visually. Harbour seals were then classified as either pups or 1+ age class. No attempt was made to further differentiate the 1+ age class.

In 2012 we surveyed the entire coast and offshore banks from Donna Nook in Lincolnshire to Blakeney Point in Norfolk on 1st July. In both 2008 and 2010 we carried out four additional surveys between 12th June and 13th July to establish the form of the pups ashore curve.

Results

2012 surveys

A total of 1469 pups and 3561 older seals (1+ age classes) were counted in the Wash on 1/07/2012. No pups were observed at either Donna Nook or at Blakeney point, the two nearest haulout sites to the north and east of The Wash respectively. Breeding season counts since 2001are presented in table 1. These were distributed over 50 separate haulout groups, although the number of sites is to some extent a function of the arbitrary division or pooling of groups.

The 2012 survey produced the highest pup count ever obtained in the Wash, the count was 25% higher than the estimated peak in 2011, but close to the peak count in 2010 (1423), which was itself 13.6% higher than the 2008 peak count. Figure 6 suggests that the trend in the counts can be approximated by an exponential increase at an annual rate of increase of 9.8% p.a. since 2001. The relatively large increases in 2005-2006, 2009-2010 and the large fall between 2010-2011 followed by an equally large increase to 2012 indicate that there is a large inter-annual variability in pup production and this is apparent in the noise about the fitted exponential in figure 1.

Estimating pup production

In each of 2008 and 2010 we obtained five counts of pups at weekly intervals between mid-June and mid-July. Figure 2 shows these counts with a simple smoothed line connecting the points. Although the curves suggest that the peak number of pups occurs around 1st July it is also apparent that the shapes of the pups ashore curves are different in the two years. To date we do not have a useful model of births and haulout patterns that can fit to the observed data in both years.

For comparison, figure 3 shows the same data for the Moray Firth from air surveys between 2006 and 2012. Again, the pattern of counts differs widely between years and seems to preclude fitting a simple model.

Variation in fecundity and/ or pup haulout behaviour

Although there is considerable variation about the line, the peak pup counts in The Wash have increased continuously since 2012. The moult counts in Wash have not increased continuously since 2002 (Figure 4). The counts continued to decline after the 2002 epidemic, apparently stabilised/levelled out around 2005-2007and have increased rapidly since then. The moult count in 2011 was similar to the 2001 count while the estimated peak pup count in 2012 was 2.7 times greater than in 2001. If the moult count is a consistent index of the total population size then the apparent fecundity of the Wash population has increased by a factor of around 2.7 since 2001.

The large inter-annual variation in peak pup count also suggests large inter-annual variation in apparent fecundity.

Discussion

The most significant event in recent years for harbour seals in the Wash was the recurrence in 2002 of a PDV epidemic. Our standard annual moult surveys indicated that the effects of this epidemic were less severe than in 1988 but there was still a significant reduction of 22% in our population index.

There was no commensurate decrease in pup production between the pre and post epidemic counts. There are several potential explanations for the lack of a decline, the most likely of which would seem to be differential mortality during the PDV epidemic or variation in fecundity. Alternative scenarios involving temporary immigration are currently thought to be less likely.

Pup production appears to vary more than could be accounted for by inter-annual changes in the adult female population. This suggests that there must be wide fluctuations in fecundity and or short term immigration and emigration of breeding females. At present we do not have information on pregnancy rates in any UK harbour seal population. Telemetry data from both the English and Dutch populations suggests that movement between the two areas is unlikely to be sufficient to account for these changes.

The more than doubling of apparent fecundity between 2001 and 2012 is a striking feature of the data. Such a change could be generated through:

- Immigration of a large number of adult females. The absence of any substantial populations on the rest of the east coast means that the source of seals would have to be either the Wadden Sea or the Scottish Eastern Scotland. Data on seal movements suggest that immigration from Scotland is unlikely and that movement between the English and European populations is unlikely to be frequent enough to explain these changes.
- A continual increase in fecundity. This again seems unlikely given the scale of the increase and its gradual nature. However, rapid inter-annual changes in both directions in pup counts may suggest wide variation in fecundity rates.

At present we have no information to allow us to differentiate clearly between these options and it is likely that a combination could be operating. However, in either case the explanation would represent a major change in harbour seal demographics.

In 2008 and 2010 we carried out a sequence of surveys to confirm the timing of the peak number ashore. This occurred on or about 28th June and 1st July respectively, confirming that the previous years' counts had been close to the peak. All counts would have been within 4% of the peak if the timing in each year was similar to the 2008 or 2010 patterns, except for 2001 when the count would have represented 90% of the peak. Timing of surveys is restricted to the weekends by RAF bombing activity so surveys will continue to be carried out on the weekend closest to the 1st July.

The pup count series from 2008 and 2010 confirm the timing of the peak count. However differences in the shape of the pup curves mean that we cannot produce a reliable model to estimate pup production. Examination of similar data for the Moray Firth population shows similarly wide variations in the shape of the pup curves and similar, apparently large changes in peak pup count which may again indicate large inter-annual variation in fecundity.

The number of pups counted on each flight results from a combination of the temporal pattern of births and temporal patterns in the proportion of time spent on the haulout sites as the pups age. Visual inspection of the pup count data suggests that both of these temporal patterns vary between years in both populations.

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Table 1. Counts of harbour seal pups and 1+ age classes in the Wash.

Year	2001	2004	2005	2006	2007	2008	2009	2010	2011	2012
Pups	548	613	651	1054	984	994	1130	1432	1106	1469
1+ age classes	1802	1766	1699	2381	2253	2009	2523	3702	3283	3561

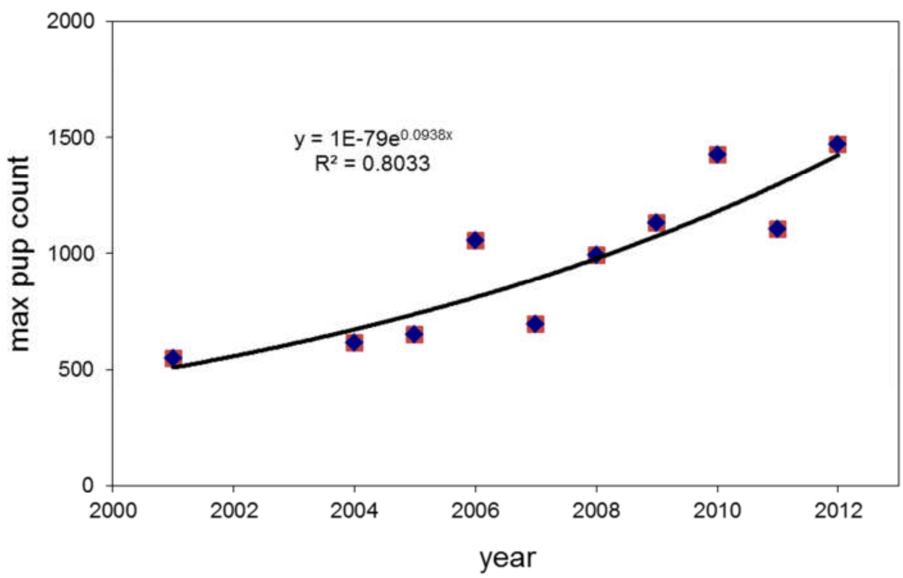

Figure 1. Maximum counts of pups in The Wash between 2001 and 2010. The fitted line is a simple exponential.

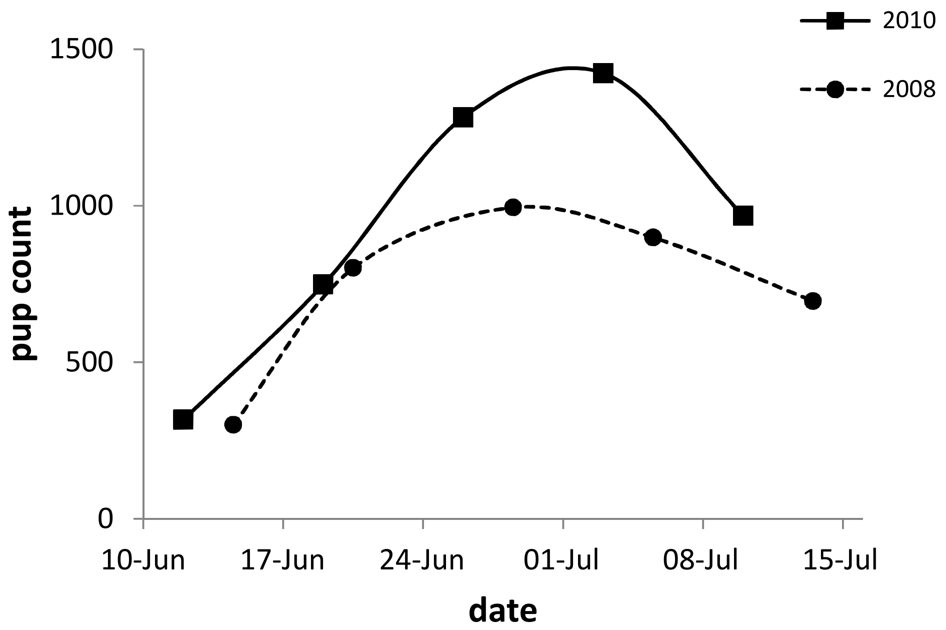

Figure 2. Aerial survey derived counts of harbour seal pups in The Wash in 2008 and 2010

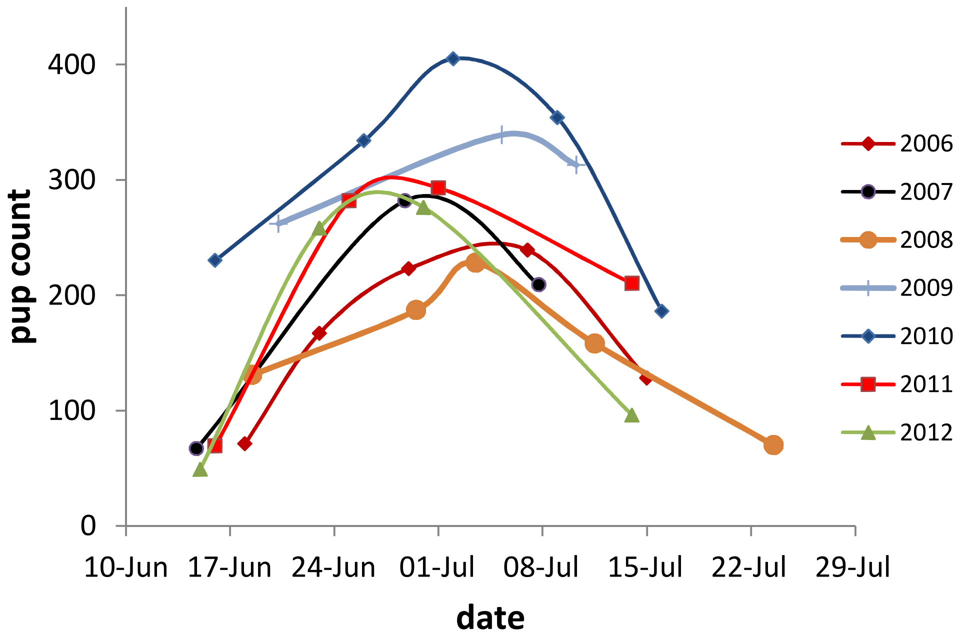

Figure 3. Aerial survey derived counts of harbour seal pups in the Moray Firth 2006 to 2012.

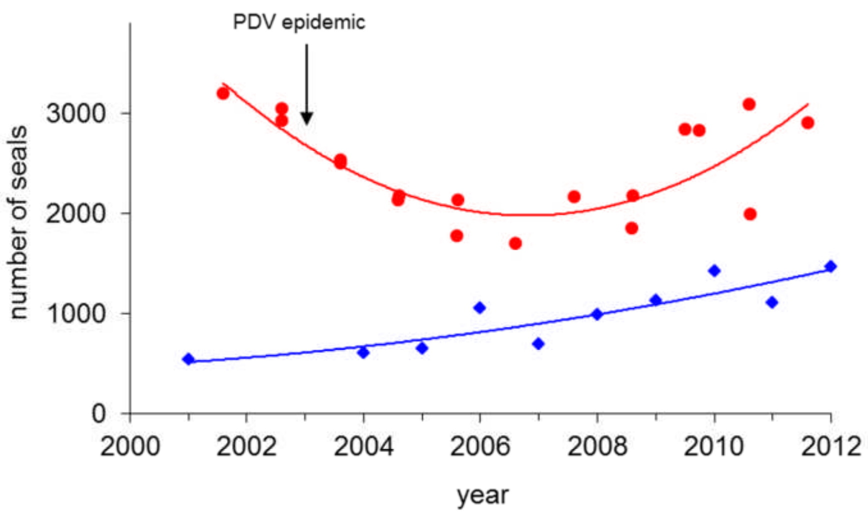

Figure 4. Maximum counts of pups in The Wash between 2001 and 2012 together with the standard moult population monitoring counts for the same area. The fitted line for the pups is a simple exponential (9.6% p.a. increase) and a simple quadratic has been fitted to the moult count data to illustrate the general trend.

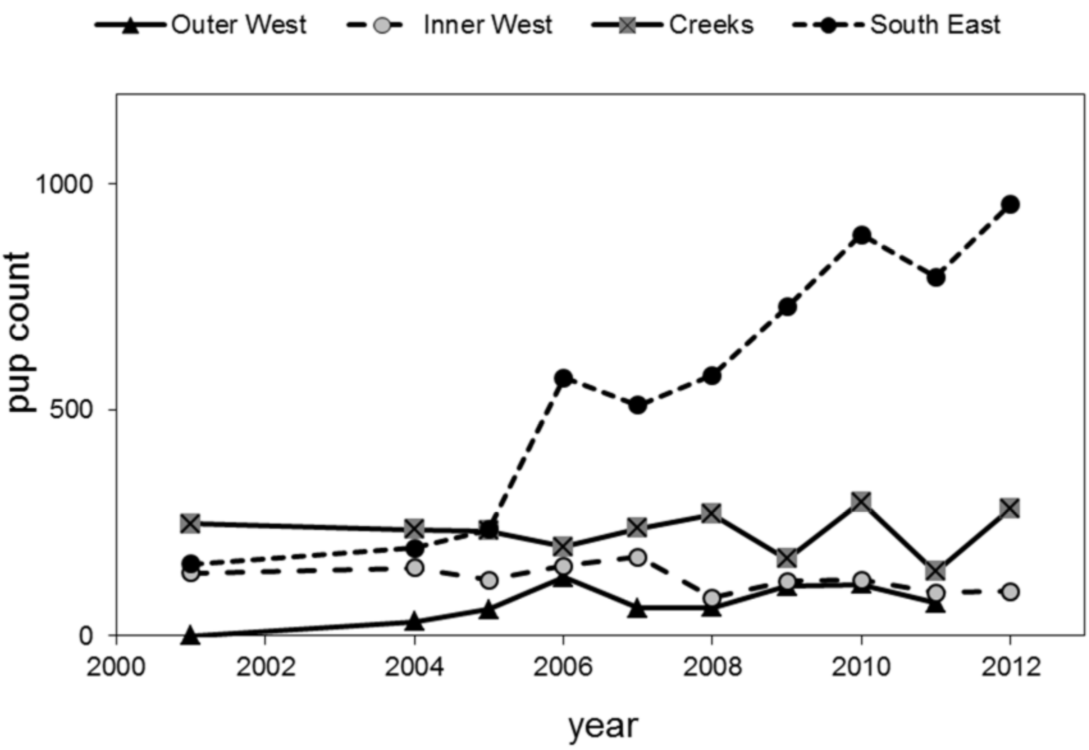

Figure 5. Distribution of harbour seal pups in the Wash during the 2001 to 2012 breeding seasons pooled into geographical sub regions (Vaughan, 1978). For 2008 and 2010 the distribution on the day of the maximum count is presented. The most dramatic change is the sudden increase in numbers of pups in the complex of banks in the south east corner of the Wash in 2006. This increased importance of these banks was maintained through to 2012 and this area now produces 65% of the pups in the Wash, up from 30% in 2001 and 2004.

Marine mammals and salmon bag-nets

Robert N. Harris and Simon P. Northridge.

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

Abstract

Wild salmon net fishers perceive seals to be adversely affecting their livelihood and thus apply for licences to shoot seals in the vicinity of their nets. Over the last four years we have investigated the extent of marine mammal activity around nets and the existence of net specialist seals. We have also investigated a number of non-lethal methods for reducing the presence of seals around nets with the aim of reducing the requirement for lethal control, and are currently evaluating a range of deployment methods. We have shown that marine mammal activity coincides with fluctuations in fishery landings and, through the use of photo-identification, that the same individuals persist around nets and consume salmon at a high rate providing evidence that net specialist seals exist. Acoustic Deterrent Devices (ADDs) have been shown to be an effective mitigation tool as they reduced seal presence, increased catch per unit effort and reduced levels of damage. The results of net modification trials are more complex and are still being analysed. Another ADD (AirMar), along with a modified pulse from an existing ADD (Lofitech) and deployment methods are being evaluated in 2013.

Introduction

Salmon net fishers have long held the belief that seals adversely affect their livelihoods by damaging and removing fish from their nets. Licences may be obtained to allow nominated marksmen to lethally remove seals that are perceived to be damaging catches. Despite a long history of lethal control at salmon net sites, seals are still perceived to be a significant problem by net fishers (Butler et al. 2011). The majority of salmon net fisher respondents to a questionnaire in the Moray Firth (Butler et al. 2011) and from other east coast bag-net sites (Harris unpublished data), believed that seal predation had a significant effect on salmon and sea trout stocks and net catches. They felt that all seals were responsible for damage, although some felt that specialist 'rogue' seals were also a problem. Most felt that seal predation should be controlled by a reduction in the size of seal populations (Butler et al. 2011).

This work is part of an on-going study funded by Marine Scotland.

Activities include dedicated periods of observation to record marine mammal presence (including photo-id at some sites), recording of salmon catches and levels of damage, experimental trials of ADDs and modified nets to evaluate the effectiveness of these mitigation measures, and wherever possible the carcasses of seals shot to protect wild salmon fisheries have been collected for diet analysis.

Main Findings to Date

Land-based Observations and Photo-identification

Peaks in seal or bottlenose dolphin activity at nets coincided with times when salmonid catches were high. Observations of aggressive interactions and possible displacement of individuals suggests that some level of hierarchy may exist at nets (both between conspecifics and between different species). Seals at nets left the area as dolphins approached and the range at which seals responded to the approach of dolphins suggested that seals were responding to acoustic cues of dolphins. This suggests that dolphin vocalizations may warrant investigation as an alternative to the high intensity sounds used by commercial ADDs. Data suggested the existence of net specialist seals (see Tables 1 and 2 showing data on seals identified at the study sites in the Moray Firth and Montrose between 2009 and 2011). The number of such net specialists was low but they returned each year, visited multiple net fishing sites and their presence at nets contributed to the majority of seal sightings at nets.

Carcass Recovery and Diet

Salmon fisheries are able to apply for a licence to shoot seals for the purpose of protecting fisheries from serious damage by seals under the Marine (Scotland) Act 2010. As part of the licence to shoot seals fisheries are expected to make an effort to recover seal carcases and make them available for collection by the Scottish Marine Animal Strandings Scheme or the SMRU. Gastro-intestinal tracts are then available for dietary analysis. Carcass recovery from salmon net sites is on-going. To date we have recovered 32 seals and have completed DNA and hard-part analysis from 16 digestive tracts. Of these, salmonids were detected in 3 carcasses (19%), results that are consistent with previous diet assessments of seals shot at salmon net sites (Rae 1968, Pierce et al. 1991) and are only slightly higher than the proportion of scat samples from estuarine haul-out sites with salmonid present – 13% (n=182, Matejusova et al. 2008), although lower than the proportion of carcasses recovered from within rivers with salmonid present - 64% (n=11, Graham et al. 2011 & Harris unpublished data).

ADD Experimental Trials

In 2009 and 2010 an experimental trial of an ADD (www.Lofitech.no) was conducted at a salmon bag-net to evaluate its effectiveness. The trial consisted of randomly assigned 'on' or 'off' periods During periods when the ADD was 'on', there were significantly fewer seals observed and significantly more salmon were landed per hour than when the ADD was 'off'. There was evidence that the higher fish landings when the ADD was operating were a direct result of the reduction in the number of seals in the vicinity of the net and the amount of time that seals spent in the area. Seal damaged salmon were only found within the net when the ADD was 'off'.

In 2011 one fishery was given the opportunity to use and maintain an ADD to determine ease of deployment by this industry. The fishery took full responsibility for the day-to-day running of the ADD. The fishers kept the ADD 'on' continuously while the net was fishing. Over the course of the season they recorded no seal damage, no seals were shot and there was a large reduction in the sightings of seals. They perceived an increase in landings to be attributed to the ADD and overall felt the device was extremely effective.

Four wild salmon net fisheries were provided with an ADD (www.Lofitech.no) in 2012. At all sites fishers were impressed with the ability of the device to keep seals away from the nets, the increase in catch per unit effort compared with times when the ADD was 'off' and the reduction in seal damaged fish. However, ADD technical failures in 2012 highlighted the need for a simpler, more robust method of deploying ADDs in this fishery.

During 2013 we evaluated a power saving modification to extend battery life and developed practical, robust deployment methods for wild salmon net fishers. In addition a second ADD device made by Airmar was evaluated through a series of 'on' and 'off' treatments. Results are currently being analysed.

Experimental Net Modification Trial

In 2012 a modified salmon net was fished in a paired trial alongside a control net to assess the effectiveness of net modifications at mitigating the effects of seals. Land-based observations and underwater video footage were collected and the analysis of these data is on-going. Preliminary results indicate that the undamaged catch per unit effort from the modified net was considerably larger (~70% larger) than the control net, however, the proportion of damaged fish was also larger in the modified net. Underwater video footage revealed that the likely reason for this difference in damage to fish is a result of the way in which seals could navigate the chambers of the control net with apparent ease and remove whole salmon. This was not possible in the modified net and therefore seals were only able to damage fish through the meshes of the net. Video observations will allow the frequency of fish removal from the inner chamber of the nets to be quantified.

Conclusions

Alongside other studies, we have shown over the last four years that reducing seal damage in the landed catch of wild salmon nets is achievable (Hemmingsson et al. 2008; Lehtonen & Suuronen 2004) and reducing the activity of seals around salmon nets is also achievable (Lunneryd et al. 2003; Harris 2011a; Fjalling et al. 2006). There are an increasing number of mitigation measures available to salmon bag-net fishers however the costs and practicalities versus benefits of each method need to be evaluated on a site-by-site basis. Although results from ADD and net modification trials were encouraging, neither method can be regarded as 100% effective and therefore the best approach will likely involve a combination of mitigation methods. The priority now is to develop practical and affordable deployment methods.

Acknowledgements

We are grateful to Marine Scotland for the continued funding of this work.

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Table 1. Summary of seals identified in Montrose study areas in 2009, 2010 and 2011 and the number of salmonids taken at the observation net (Hg = grey seal, Pv = harbour seal)

Seal ID	Date		No. of sightings	No. of years seen	No. of net sites	Salmonid	
	1st seen	Last seen				Whole	Part
Hg101	20/05/2009	25/08/2011	12	3	2	3	0
Hg102	13/07/2009	26/07/2011	15	3	2	11	0
Hg104	16/08/2010	13/07/2011	4	2	1	0	0
Hg106	22/07/2011		1	1	1	0	0
Hg107	26/08/2011		1	1	1	0	0
Hg108	31/08/2011		1	1	1	0	0
Pv101	20/05/2009		1	1	1	0	0
Pv102	09/07/2009	29/08/2011	11	3	3	0	2
Pv103	11/06/2010	29/08/2011	3	2	2	0	1
Pv104	22/06/2010	23/06/2010	2	1	1	0	0
Pv106	10/06/2011	14/06/2011	2	1	2	0	0
Pv107	28/06/2011		1	1	1	0	0

Table 2. Summary of seals identified in Moray Firth study areas in 2009 and 2010 and number of salmonids taken at the observation net (Hg = grey seal, Pv = harbour seals)

Seal ID	Date		No. of sightings	No. of years seen	No. of net sites	Salmonid	
	1st seen	Last seen				Whole	Part
Hg111	22/07/2009	07/08/2009	3	1	1	0	0
Hg112	27/07/2009	-	1	1	1	0	0
Hg113	30/07/2009	12/08/2010	3	2	1	0	0
Hg114	11/08/2009	-	1	1	1	0	0
Hg115	11/08/2009	-	1	1	1	0	0
Hg116	14/08/2009	11/08/2010	14	2	2	11	0
Hg212	22/07/2010	28/07/2010	3	1	1	0	1
Hg217	29/07/2010	06/08/2010	2	1	2	0	0
Hg219	21/07/2010	-	1	1	1	0	0
Pv211	23/07/2010	-	1	1	1	0	0
Pv214	09/08/2010	-	1	1	1	0	0

Pinniped strandings in Scotland 1992-2012

Andrew C. Brownlow, Nick Davison and Geoff Foster

SRUC Wildlife Unit, Drummondhill, Inverness IV2 4JZ

Abstract

The Scottish Marine Animal Stranding Scheme's purpose is to monitor and collate marine animals stranding data, with the aim of assessing the health of, and threats to, Scotland's marine mammal population. Information gained includes cause of death; indicators of health, pathogen prevalence and assessment of overall disease burden. Additionally, samples are collected and archived for subsequent analysis for a range of research questions. To date the scheme has shown that, for pinnipeds, physical trauma is the most common cause of death (50%) and includes animals shot or those with the emerging 'corkscrew' or spiral lesions. The most common infectious disease was verminous pneumonia with pneumonias in general accounting for 13% of all mortalities. Starvation represents 14% of deaths although this cohort was largely comprised of neonatal pups. The data suggest a significant proportion of mortality of examined cases can be attributable, directly or indirectly, to human activities. Care is however needed with inferences made from strandings data alone, as recovered carcasses may not be representative of the population and heterogeneity of reporting effort between coastal regions likely further bias the data.

Introduction

The Scottish Marine Animal Stranding Scheme has been in operation since 1992. It is funded by the Scottish and Westminster governments to monitor and collate marine animal stranding data, with the aim of assessing the health of, and threats to, Scotland's marine animal species. Strandings are collated by the SRUC Wildlife unit in Inverness and a subset of cases are collected for necropsy. Examination of animals at post mortem can provide information on cause of death, assess indicators of health and disease burden and provide samples for subsequent analysis for a range of research questions. The strandings work forms part of the Cetacean Strandings Investigation Programme (CSIP), a consortium of partner organizations providing UK wide monitoring of marine animals. The stranding scheme in England and Wales originated in 1990 in response to the 1988 phocine distemper virus (PDV) outbreak, although seals were subsequently dropped as a monitored species in the early nineties and, with the exception of the 2002-2003 PDV outbreak, have since remained out of the scheme in England and Wales. In Scotland between 1992 and 2009, funding for seals was discontinuous, however since 2009 specific funding has been made available by Marine Scotland to support seal necropsies. Prior to 2009 the data is heavily influenced by these variations in effort however subsequently a more consistent picture has been achieved.

Table 1: Pinniped strandings 1992-2012

Year	Not necropsied	Necropsied	Total
1992	187	29	216
1993	236	48	284
1994	280	42	322
1995	199	13	212
1996	83	22	105
1997	86	9	95
1998	46	13	59
1999	38	18	56
2000	42	12	54

2001	22	6	28
2002	739	83	822
2003	223	19	242
2004	82	4	86
2005	82	8	90
2006	99	9	108
2007	87	6	93
2008	74	2	76
2009	60	10	70
2010	138	61	199
2011	251	26	277
2012	223	44	267
Total	**3277**	**484**	**3761**

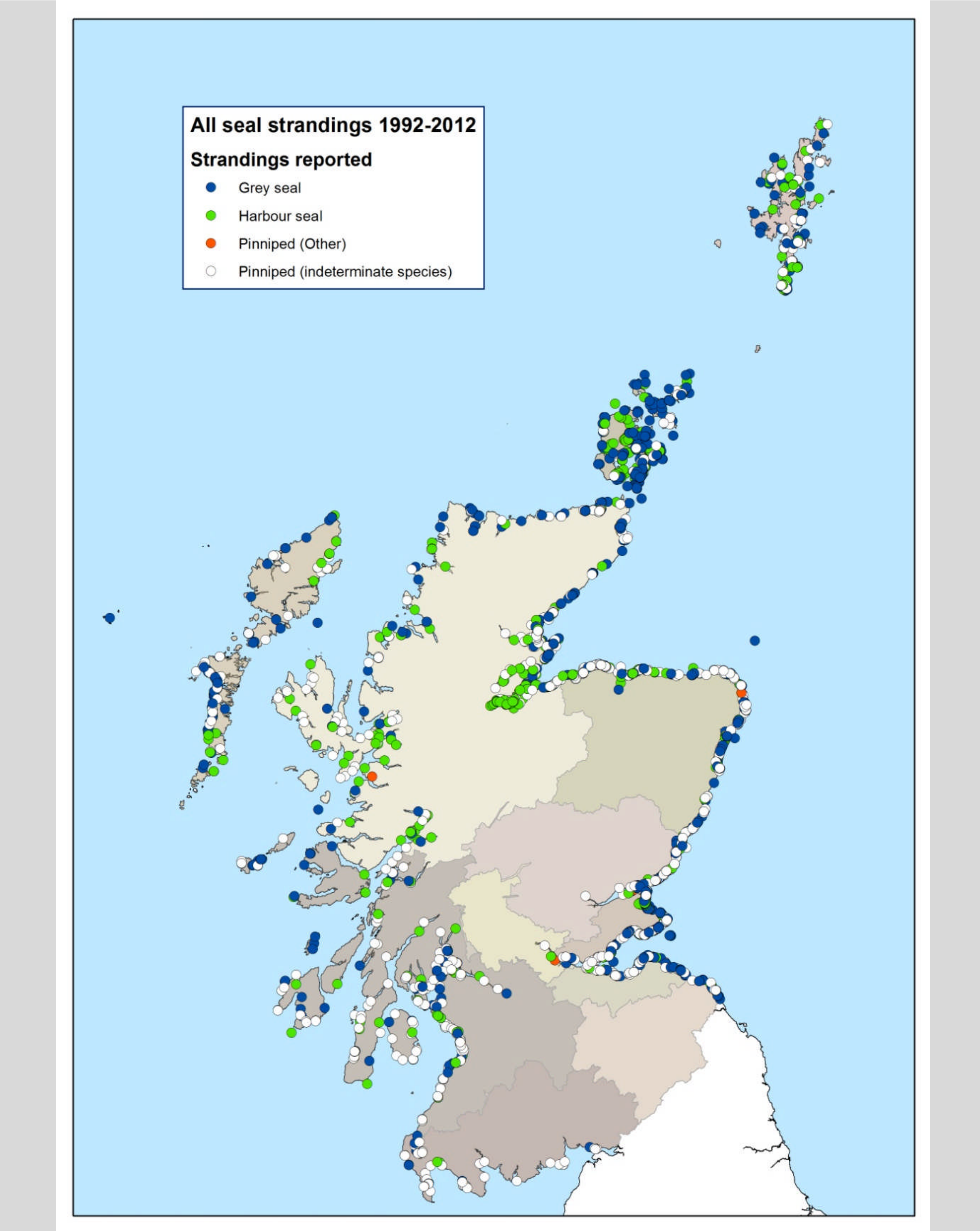
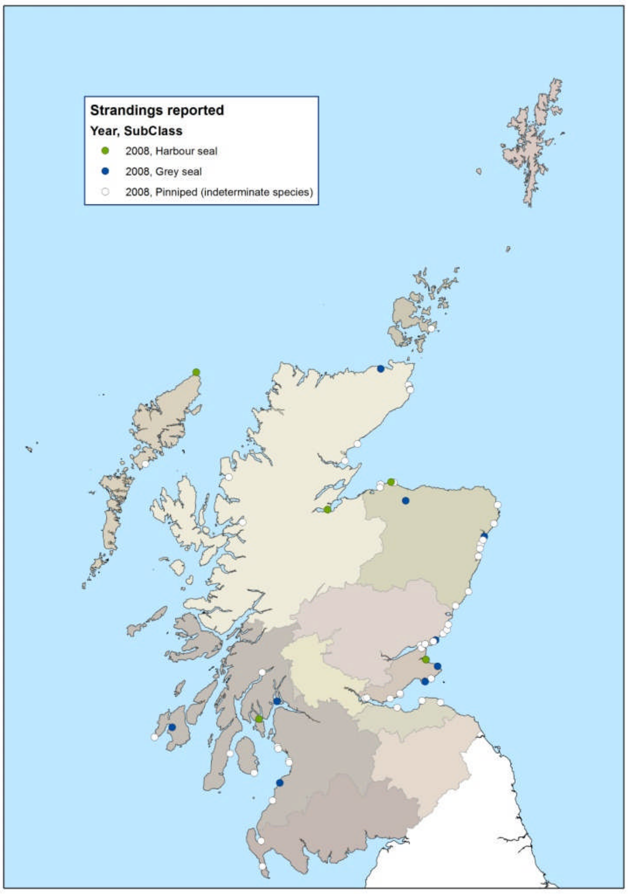


Figure 1: All seal strandings 1992-2012

Table 1 and Figure 1 above summarise all seal strandings in Scotland 1992-2012. Figure 2 and 3 highlight the impact of reporter effort and show the difference in stranding numbers before and after efforts were made to publicise the stranding scheme and increase reporting .



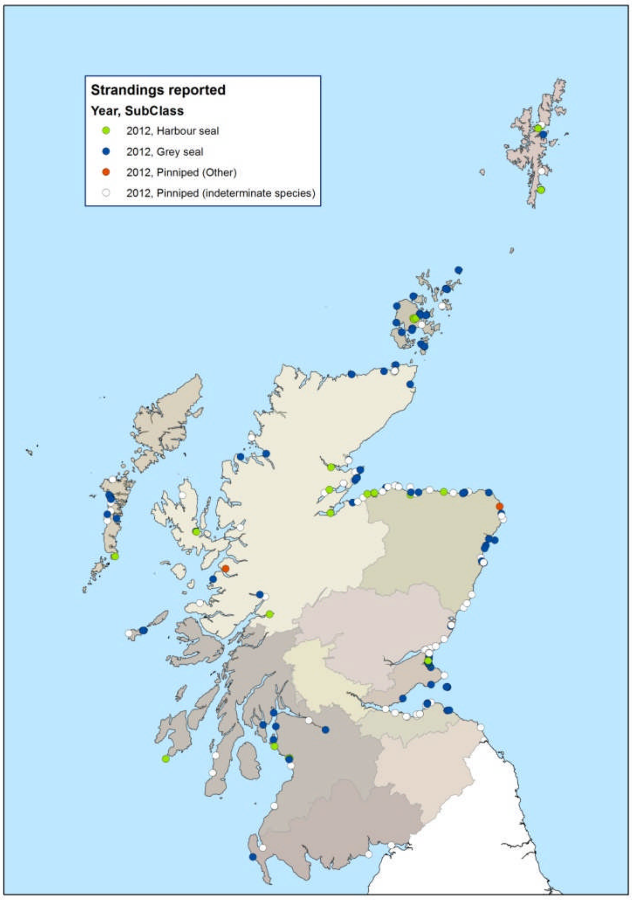


Figure 2: Pinniped cases 2008

FIGURE 3: **PINNIPED CASES 2012**

2012 Strandings

267 pinnipeds were reported stranded in 2012. The most commonly reported species was the grey seal (Halichoerus grypus) representing 46% of pinniped strandings. Harbour (common) seals (Phoca vitulina) account for 15% of pinniped strandings. Unidentified seals account for 45% of pinniped strandings and 22% of all marine mammal 2012 stranding reports (103 individuals). A single bearded seal (Erignathus barbatus) was the first record for this species since the project began.

The proportion of reported seal strandings necropsied in 2012 was 16.5% (n=44), whereas in comparison the proportion of cetaceans necropsied was 45%. The difference is mainly due to a high proportion of these cases being in an advanced state of autolysis when reported (51%) or the reporter not supplying sufficient data for the animal to be successfully located (25%).

Grey seal (Halichoerus grypus)

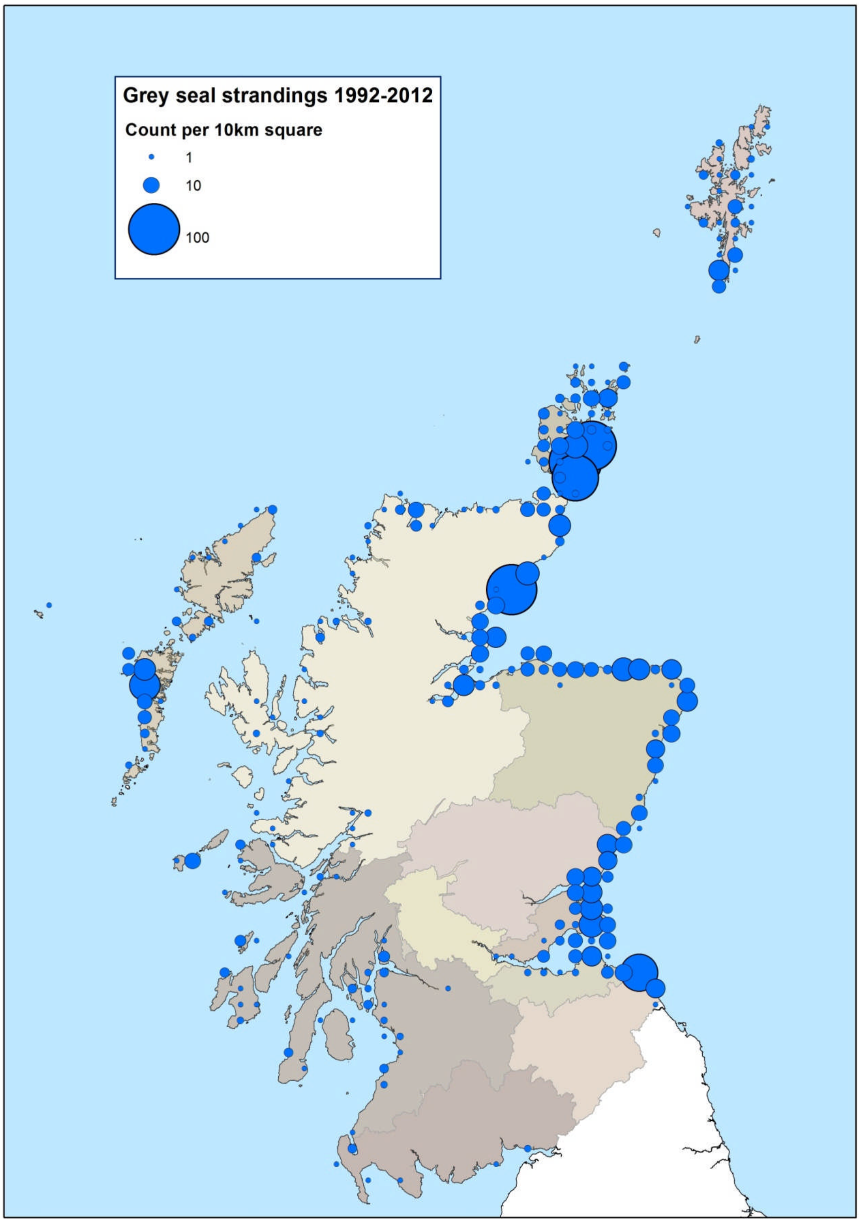


Figure 4: Grey seal stranding density 1992-2012

Figure 4 above shows density of strandings reported and highlights the east-coast bias in strandings reports. This pattern is thought to represent a combination of density of seal populations and reporting effort.

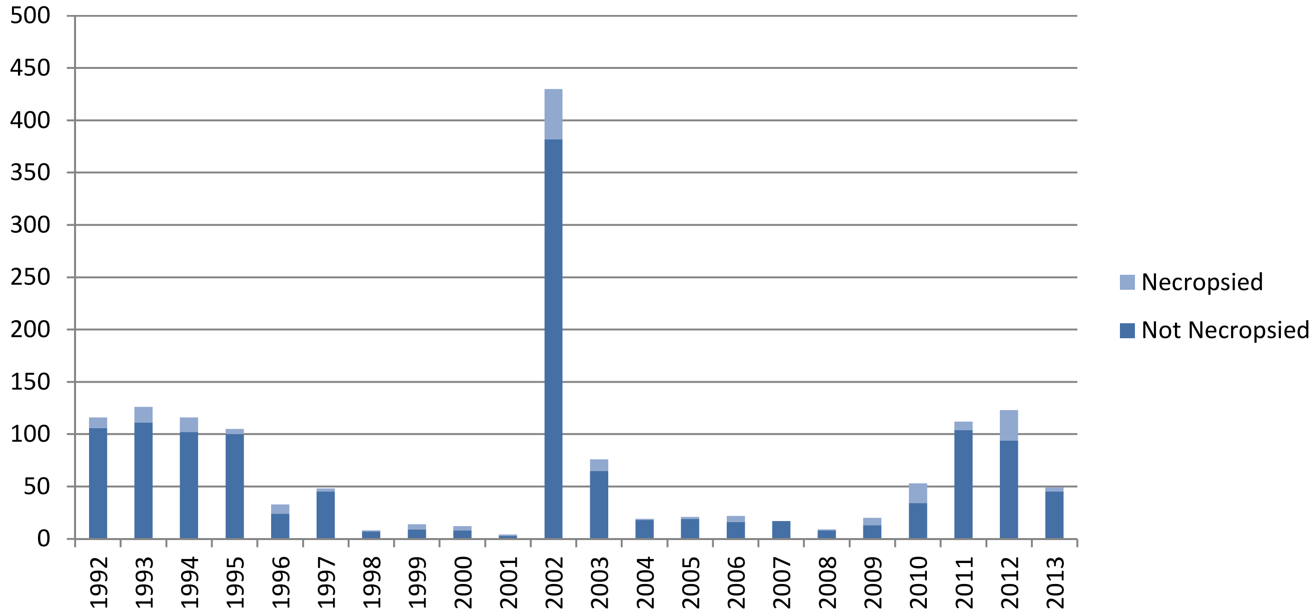


Figure 5: Grey seal strandings reports 1992-2012

Figure 5 shows trends in stranding numbers for grey seals. Between 1992 and 1995 the peaks represent seals shot as part of culling strategies. Increased survey effort during the 2002/3 phocine distemper outbreak resulted in an increase in stranding reports, demonstrating the effect of active surveillance. Equally, following publicity campaigns from 2009 onwards, it is considered that the increase in reporting is due to an increase in awareness and effort rather than increased mortality.

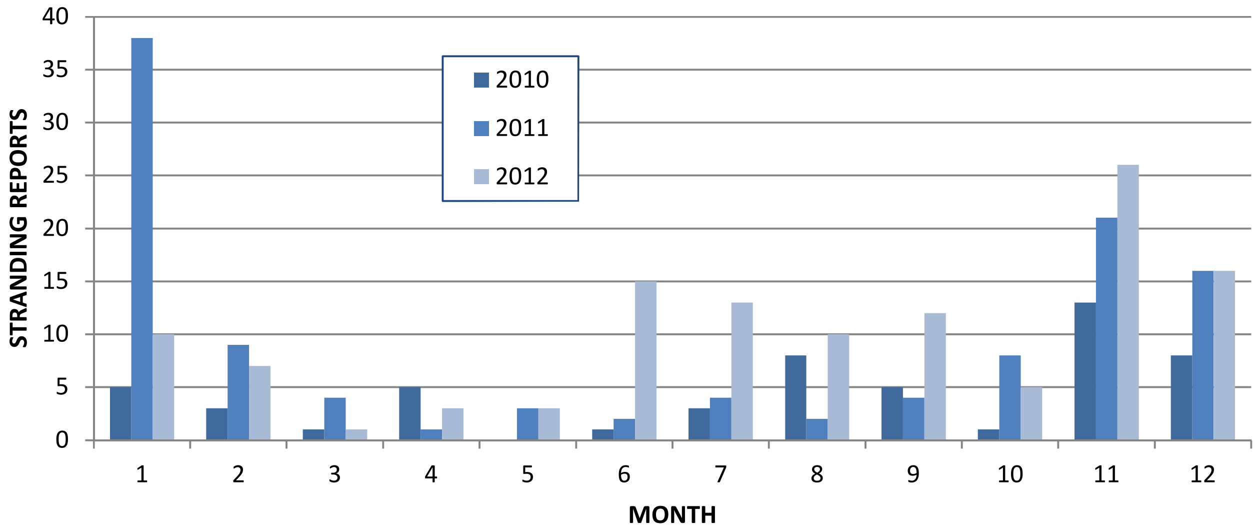


Figure 6: Monthly grey seal stranding reports 2010 - 2012

Figure 6 above shows the monthly trend in grey seal strandings, with a marked increase between November and January, coinciding with the pupping season. The peak seen in January 2011 was due to high number of mortalities reported by SMRU from the Fast Castle, Berwickshire pupping site.

Harbour (Common) Seal *(Phoca vitulina)*

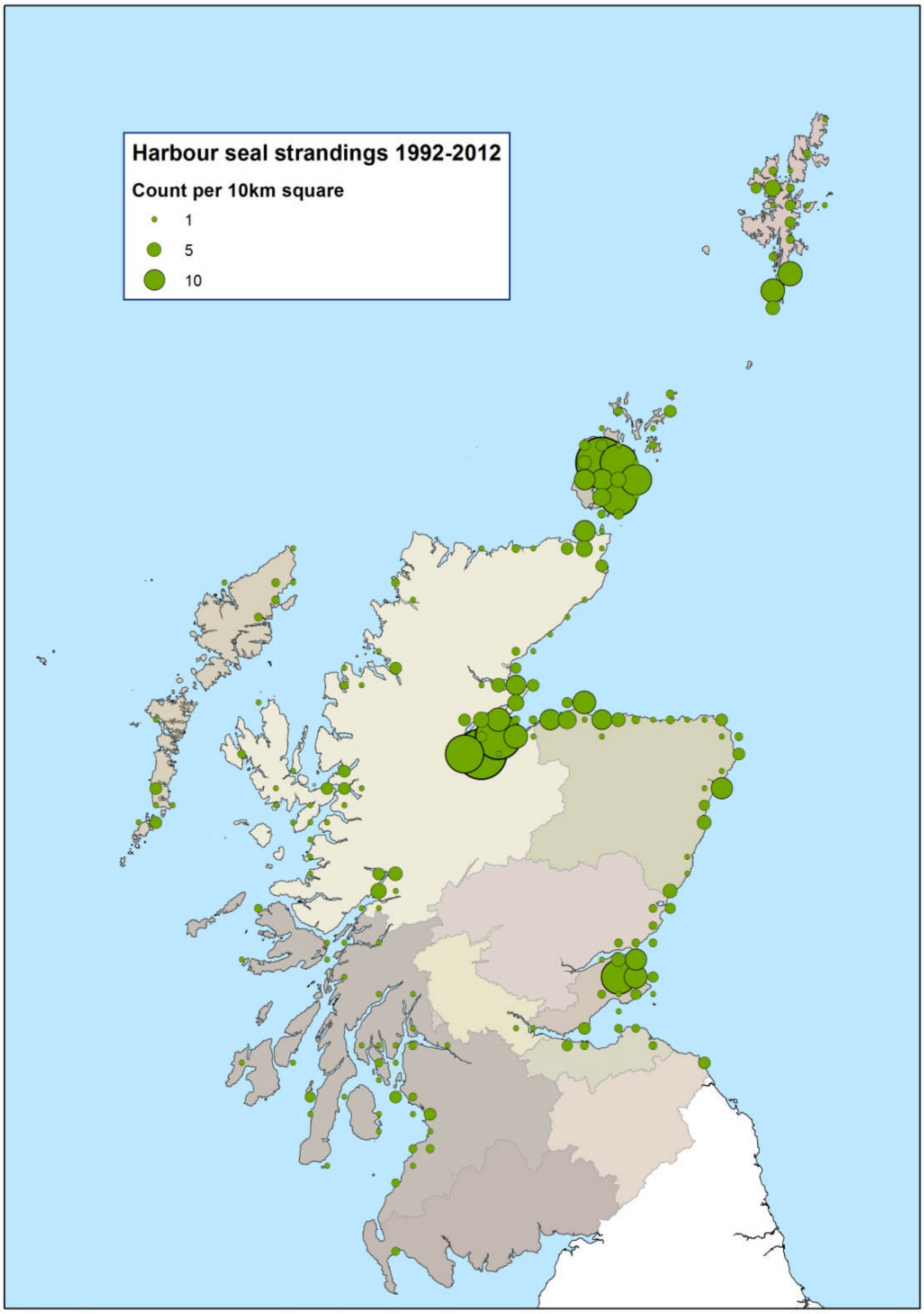


Figure 7: Harbour (common) seal stranding density 1992-2012

Figure 7 shows the common seal stranding density. Numbers are lower than grey seal and the distribution represents a combination of density of seal populations and reporting effort, most notably around the Moray Firth.

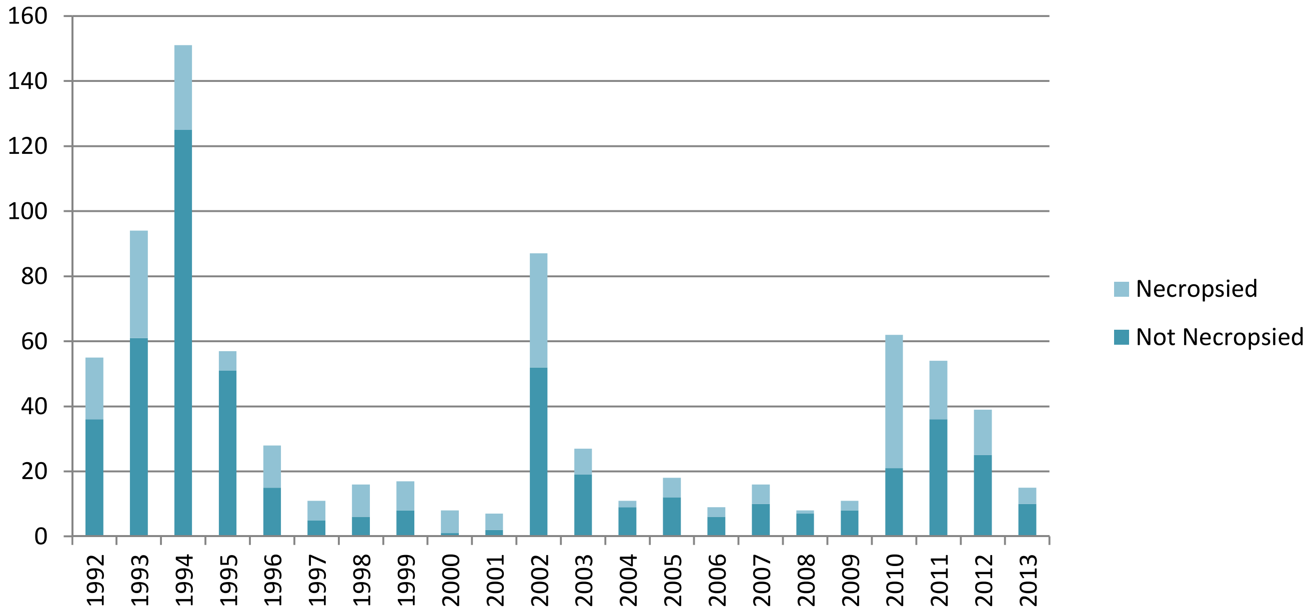


Figure 8: Annual harbour (common) seal strandings reports 1992 – 2012

Figure 8 above shows historic peaks in harbour (common) seal strandings. Similar to grey seal reports, increased survey effort during the 2002/3 phocine distemper outbreak resulted in an increase in stranding reports. It is of note that fewer than 20% of cases reported during the PDV outbreak were diagnosed with morbillivirus as the primary cause of death. From 2010 onwards it is thought that the increase in reporting is due to an increase in awareness and effort and represents a more accurate picture of harbour (common) seal strandings.

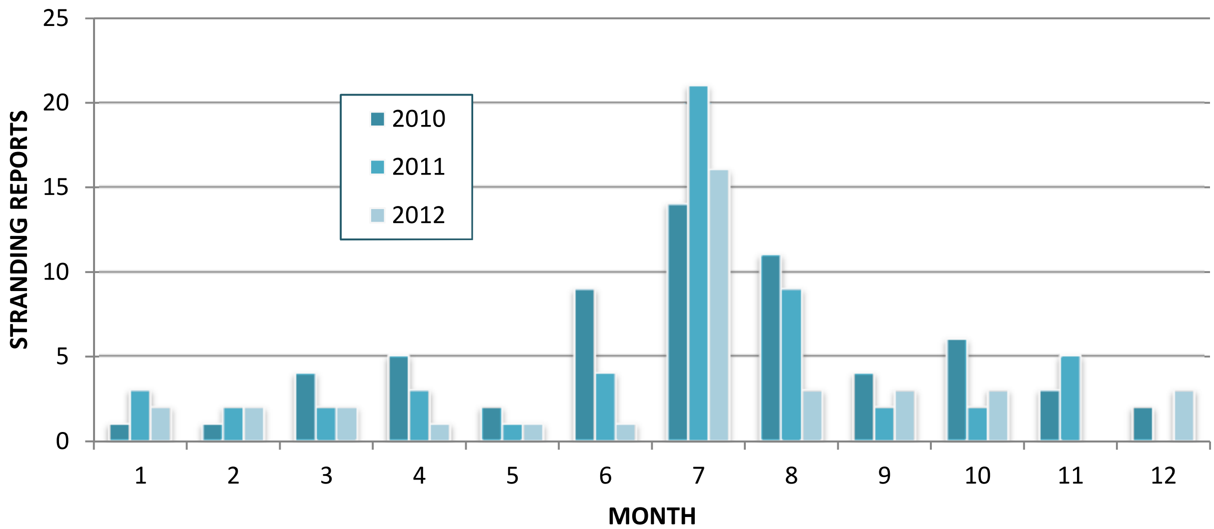


Figure 9: Monthly harbour (common) seal stranding reports 2010 – 2012

The 2012 monthly trend in harbour (common) seal strandings is similar to previous years showing a marked increase between June and August, coinciding with the pupping season.

Underreporting

With both seal species, it is considered there remains a significant degree of underreporting. This constrains the use of stranding counts alone as an accurate metric of population mortality, nonetheless, since 2009, reporting rates have improved and provide some indication of minimum mortality rates. Increased efforts are however underway to further increase the reporting and recovery rate for seals through public outreach events. By mid 2013 there were some indications of an improvement in areas where these events had been trialled.

Cause of death

Table 2 below shows the causes of death established following necropsy. Physical trauma is the most common cause of death (50%) and includes animals shot or those with the emerging 'corkscrew' or spiral lesions. The most common infectious disease was verminous pneumonia with pneumonias in general accounting for 13% of all mortalities. 14% of deaths were due to starvation and comprised largely of neonatal pups.

Table 2: Common causes of death

Cause of death	Grey seal	Harbour seal	Pinniped (Other)	Total
Trauma	**84**	**120**		**204**
Physical Trauma	74	112		186
Dystocia & Stillborn	2	5		7
Entanglement & Bycatch	8	3		11
Infectious disease	**57**	**73**	**3**	**133**
Pneumonia, Parasitic	11	33	1	45
Generalised Bacterial Infection	20	17	2	39
Morbillivirus	17	14		31
Pneumonia, Parasitic and Bacterial	5	5		10
(Meningo)encephalitis	2	1		3
Gastritis and/or Enteritis	2	1		3
Generalised parasite burden		2		2
Other	**28**	**52**	**6**	**86**
Starvation	19	38	1	58
Others	32	38	5	75
Neonatal Death	1	5		6
Euthanasia	5			5
Dystocia & Stillborn	2			2
Developmental abnormality		1		1
Total	**200**	**275**	**9**	**484**

Bacteriology

There have been a number of newly discovered bacteria isolated from pinnipeds in Scotland and elsewhere in the UK as a result of post mortem examinations carried out under the scheme these include *Streptococcus halichoeri* (Lawson et al 2004), *Streptococcus marimammalium* (Lawson et al 2005), *Corynebacterium phocae* (Pascual et al 1998), *Atopobacter phocae* (Lawson et al 2000), *Bisgaardia genomospecies 1* (Foster et al 2011). This last organism was involved in a human infection following a seal bite. Other notable bacterial pathogens are highlighted below.

E.coli
The most commonly isolated organism from seals with over 40 isolations. It may represent an opportunistic pathogen in some cases.
Streptococcus phocae
Originally isolated from seals with pneumonia (Skaar et al 1994) this pyogenic species adapted to seals is isolated on a frequent basis from both common and grey seals. It has been isolated from both respiratory and alimentary tracts of pinnipeds as well as other sites and appears to be an opportunistic pathogen. *Streptococcus phocae* has been implicated in many diseases including pneumonia, infected bite wounds and septicaemia, often in association with other likely opportunists.
Arcanobacterium phocae
A coryneform whose major habitat is pinnipeds, particularly associated with wounds, skin lesions and eye conditions, though has been isolated from the respiratory tract. (Ramos et al 1997)
Brucella
Brucella pinnipedialis, (Foster et al 2007) and organism first reported in seals was discovered as part of routine investigations in 1994 (Ross et al 1994) has been recovered from 4 species of pinniped in Scotland. Evidence of this organism has been detected in in pinnipeds throughout the world's oceans. Brucellosis infection in terrestrial mammals has major effects on reproductive success causing infertility, stillbirth and spontaneous abortion. This organism needs more study to determine the impact it may have on pinniped populations in particular its effect on reproductive success.
Salmonella
Salmonella Bovis-morbificans seems to be an important pathogen causing mortality in grey seal pups (Bailey et al SCOS 2013). Though its role in disease in adult animals is less well understood. This organism has not been recovered from common seals to date, suggesting it may have a preference for grey seals. *Salmonella* Bovis-morbificans is a recognised of occasional disease outbreaks in cattlein Scotland and mostly sporadic cases in humans. It has also been recovered from wild birds and an otter in Scotland. Several other Salmonella serotypes have been isolated from pinnipeeds in the UK. *Salmonella* Typhimurium dt 12 has been isolated from both common seals and grey seals. *Salmonella* Typhimurium dt 49 and *Salmonella* Newport has been isolated from common seals (Baker et al 1995). *Salmonella* enteriditis dt 8 has been isolated from infected bite wounds of a grey seal in the UK (Davison et al 2010). *Salmonella* Typhimurium DT104 has also been found in a grey seal (Foster et al 1998). There is potential for more serotypes to emerge if more animals are examined. There is potential for spill over to other species of wildlife, livestock and humans.
Mycoplasma species
Mycoplasma phocIcerebrale is the cause of seal finger in man following bites and guts from handling seals and there products. It is often associated with infected bite wounds of seals, and joint lesions where it can cause chronic osteomyelitis, this can result in amputation of the digit both in the infected seal and in human infections. It appears to be commensal in the oral cavity of seals though it has been isolated, from lungs, nose and eyes of seals. Transmission is by biting and therefore is of concern to seal biologists and rescuers. *Mycoplasma phocidae* was originally isolated from the respiratory tract of common or harbour seals in the USA where it appeared to contribute to respiratory disease in association with influenza virus but may be capable of causing severe wound infections when they penetrate the skin it has been found in a flipper wound in a grey seal and respiratory tract of a common seal in the UK. *Mycoplasma phocarhinis* has been isolated from the teeth of common seals and the lung of a grey seal with pneumonia in Scotland (Ayling et al 2011). A number of other novel Mycoplasma species have been recovered from seals in Scotland.

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