Scientific Advice on Matters Related to the Management of Seal Populations: 2012

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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 a NERC Collaborative Centre at the University of St Andrews and a delivery partner of the National Oceanography Centre. SMRU also provides government with scientific reviews of applications for licences 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 2012. It begins with some general information on British seals, gives information on their current status, and addresses specific questions raised by the Marine Scotland, Science (MSS) and the Department of the Environment, Food and Rural Affairs (Defra). Appended to the main report are briefing papers, used by SCOS, 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 over the next 5-year period. As a consequence of these cuts there was a reduced field work effort in 2011 that has had a direct impact on the advice available in 2012. An update on the financial status of the research program that supports SCOS was presented to the 2012 committee meeting.

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 generalists, feeding mainly on the sea bed at depths 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, USA, 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. 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 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 (*Phoca vitulina*) 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 (Table 3), with declines since 2000 of 68% in Orkney, 50% in Shetland, and 90% 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. 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. 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 recent 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. 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 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 will require formal status assessments for these sites in 2013. These assessments will have implications for the workload of SCOS in 2013.

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

Current status of British grey seals

- Due to financial constraints, no pup aerial surveys were carried out in 2011 in Scotland, so no new pup production estimates are available,
- The most recent UK grey seal pup production estimate in 2010 was 50,200 (95% CI 47,500-52,900)
- Pup production remained stable in the Inner and Outer Hebrides.
- Pup production increased by 6% in Orkney in 2010.
- Pup production continued to increase rapidly in the English east coast colonies increasing by 6% at the Farne Islands and 30% at Donna Nook, Blakeney and Horsey colonies between 2010 and 2011.
- Total UK grey seal population at the start of the 2010 breeding season was estimated to have been 111,300 (95% CI 90,100-137,700). This is considered to be the current best estimate and will be used for the advice.
- Use of new prior distributions for the population parameters produced a preliminary revised estimate for the total UK grey seal population at the start of the 2010 breeding season of 104,200 (95% CI 85,300-130,000).

1.1. Pup production

As part of SMRU's response to budget cuts there was no grey seal breeding season survey in 2011. Therefore the information on pup production at Scottish colonies has not changed since SCOS 2011 and the details in SCOS–BP 11/1 are the most recent data available. The total number of pups born in 2010 at all annually surveyed colonies was estimated to be 44,900 (95% CI 44,226-4,,522). Regional estimates 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 and East Anglia). 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). Pup production estimates for annually monitored colonies in Scotland have confidence intervals derived from an estimation model fitted to a series of structured pup counts. Estimates from English and Welsh colonies are derived from ground count data and have unknown confidence intervals. Overall confidence intervals were estimated assuming that the ground count estimates had similar C.V.s to the annually counted sites.

1.2. Trends in pup production

As part of SMRU's response to budget cuts there was no grey seal breeding season survey in 2011. Therefore the information on pup production at Scottish colonies has not changed since SCOS 2011. Colonies on the east coast of England are monitored by 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 (Donna Nook, Blakeney and Horsey) increased by 30% between 2010 and 2011. The English North Sea colonies represent only a proportion of the overall North Sea population so we cannot 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.

Details of the trends in pup production up to 2010 were presented in SCOS 2011 and in SCOS-BP 01/11. Briefly this showed that there has been a continual increase in pup production since regular surveys began in the 1960s. 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. The rate of increase in Orkney has declined since 2000 although pup production continues to increase gradually. Pup production at colonies in the North Sea continues to increase exponentially, although the increase has apparently slowed at the Farne Islands and the increase is mainly due to 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. The differences in pup production between 2009 and 2010 are shown in Table 1. Total pup production at annually monitored colonies increased by 6% between 2009 and 2010, compared to an increase of 1.9% between 2008 and 2009 and 6.9% between 2007 and 2008.

Within the North Sea, pup production at the southernmost colonies in Lincolnshire and East Anglia has been growing at more than 15% p.a. for the last 10 years (Table 1 & SCOS BP 11/01) and increased by over 30% between 2010 and 2011. This rate of increase probably indicates that seals from outside the local area are recruiting into the breeding population in the southern North Sea.

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

Location	2010 pup production	Change in pup production from 2009-2010	Average annual change in pup production from 2005-2010
Inner Hebrides	3,391	-0.1%.	0.0%
Outer Hebrides	12,857	+6.1%	+0.9%
Orkney	20,312	+6.1%	+2.9%
Isle of May + Fast Castle	4,249	+5.0%	+8.8%
All other colonies incl Shetland & mainland	** 3,300	+1.5%	
Total (Scotland)	**44,109**	*** +5.1%**	*** +2.2%**
Donna Nook +East Anglia	**** 3,345	***** +30.3%	+15.0%
Farne Islands	**** 1,603	***** +6.9%	+5.7%
SW England (last surveyed 1994)	250		
Wales ***	1,650		
Total (England & Wales)	**5,965**	*** +8.7%**	*** +6.7%**
Northern Ireland	100		
Total (UK)	**50,174**	*** +5.5%**	*** +2.8%**

* Average annual change in pup production calculated from annually monitored sites only
** Estimate from several surveys in Shetland to provide most up-to-date estimate
*** Estimate from indicator sites in 2004-05, multiplier derived from 1994 synoptic surveys
**** Ground count estimates for 2011 breeding season
***** Change in pup production from 2010-2011

1.3. Population size

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. 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, single maximum likelihood 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 09/2,10/2 & 11/2) has resulted in reduced population growth rates in the Northern and Western Isles. Fitting Bayesian state space models 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 06/7, 09/2). 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 10/4 &11/6).

In the absence of new pup production estimates and the continuing analysis of the prior distributions used in the model fitting process SCOS recommends that the published estimate of total population sizes from SCOS 2011 be used as the current, best estimate of total population size.

The estimated population size associated with all annually monitored colonies in 2010 was 99,300 (95% CI 80,200-122,900) for the model incorporating the independent estimate. Details of the models and fitting process are presented in SCOS BP 11/2. A comprehensive survey of data available from the less frequently monitored colonies was presented in SCOS BP 11/1. Total pup production at these sites was estimated to be approximately 5,300 in 2010. 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 produces a population estimate of 12,000 (approximate 95% CI 9,900 to 14,800) for these sites. Combining this with the annually monitored sites gives an estimated 2010 UK grey seal population of 111,300 (95% CI 90,100-137,700).

The trajectory of the pup-survival model indicates that the grey seal population increased by around 0.4% between 2009 and 2010 and has been increasing at an average of 1% p.a. for the last 10 years. Almost all of the increase has occurred in the North Sea population. The population in the Western Isles has not changed since 2000 and the Orkney population has increased by approximately 0.5% p.a. since 2000. The North Sea population has increased at around 4.5% p.a. since 2000.

In 2011 SCOS expressed concerned that the priors on several of the model input parameters were based on little information and that these might have had significant effects on the model fits. All priors used in the models were re-examined. Where new information was available it was incorporated and where necessary historical raw data were re-analysed (SCOS-BP 12/02). The resulting “new” priors were generally less informative than those used previously. These “new” priors were used to re-fit the two competing density dependent population dynamics models (preliminary results are presented in SCOS-BP 12/01) using pup production estimates from 1984 to 2010.

Incorporating the new less informative priors reduced the estimate of total population based on the model incorporating the independent population estimate. The estimated population size associated with all annually monitored colonies in 2010 was revised down to 93,000 (95% CI 76,100-116,300). Details of the models and fitting process are presented in SCOS BP 12/1.

The reduction appears to result from an increase in the uncertainty around the mean estimate. The confidence intervals of the EDDSNM estimate based on fitting to the pup production data alone increased from 0.75-1.32 times the mean estimate to 0.66-1.46 times the mean estimate. This in turn meant that when the independent estimate was incorporated it had even greater influence on the fit and pulled the mean estimate down.

The fit to the new priors also produced significantly different posterior estimates for some parameters, in particular adult survival which increased to 0.99 and maximum pup survival which was reduced to 0.29. However, the model fit included the fixed historical estimated sex ratio of 1♀:0.73♂. SCOS-BP 12/02 provides a prior distribution for the sex ratio. Additional runs of the model fitting the sex ratio will be available to SCOS 2013.

1.4. Population Trends

There is no new information on pup production at Scottish colonies since 2010. Ground count data from 2011 at colonies on the east coast of England showed that pup production continued to increase, growing by 6% at the Farne Islands and by over 30% at southern North Sea sites between 2010 and 2011. The long term average rates of change suggest that the growth of pup production in the Inner and Outer Hebrides has effectively stopped with little change in the Inner Hebrides and possibly a small decrease in the Outer Hebrides since the mid 1990s. The rate of increase in pup production in Orkney also appears to have reduced since the end of the 1990s (SCOS-BP 11/1 & 11/2; SCOS-BP 06/4). 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.

1.5. 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 2). 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 2. Relative sizes of grey seal populations. Pup production estimates are used because of the uncertainty in overall population estimates

Region	Pup Production	Years when latest information was obtained	Possible population trend[2]
UK	50,200	2010	Increasing
Ireland	1,600	2005	Unknown[1]
Wadden Sea	500	2010	Increasing [2]
Norway	1,300	2008	Unknown[3]
Russia	800	1994	Unknown[2]
Iceland	1,200	2002	Declining[2]
Baltic	4,700	2007	Increasing[2,5]
Europe excluding UK	**10,100**		**Increasing**
Canada - Sable Island	62,000	2010	Increasing[4]
Canada - Gulf St Lawrence + Eastern Shore	14,200	2010	Declining[6]
USA	2,600	2008	Increasing[7]
WORLD TOTAL	**139,100**		**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] 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, & Sunnset BH. (eds) 2011.Havforskningsrapporten 2011. *Fisken og havet*, 2011(1).
[4] W.D. Bowen, C. den Heyer, J.I. McMillan, and M.O. Hammill. 2011. Pup Production at Scotian Shelf Grey Seal (*Halichoerus grypus*) Colonies in 2010. DFO Can. Sci. Advis. Sec. Res. Doc. 2011/066: vi + 25p.
[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] 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.
[7]NOAA (2009) http://www.nefsc.noaa.gov/publications/tm/tm219/184_GRSE.pdf

Current status of British harbour seals

- Combining the most recent counts (2007-2011) a total of 26,260 harbour seals were counted in the UK. Scaling this by the estimated proportion hauled out produced an estimated total population of 36,500:
    - 80% in Scotland; 15% in England; 5% in Northern Ireland
- Compared with the mid 1990s, some populations have declined by:
    - 50% in Shetland; 68% in Orkney; and 90% in the Firth of Tay.
- Other populations do not show consistent declines:
    - Strathclyde is unclear having declined slightly after an apparent increase around 2000
    - The west coast of Highland region appears to be stable
    - The Moray Firth count declined by 50% before 2005, remained reasonably stable for 4 years then increased by 40% in 2010, and then fell by 30% in 2011
    - The Outer Hebrides apparently declined by 35% between 1996 and 2008 but the 2011 count was >50% higher than the 2008 count.
- The 2011 English East coast counts were 8% lower than 2010 and similar to those in 2009. The population estimate is now close to pre 2002 PDV epidemic levels.

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 12/03. 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. 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.

Combining the most recent counts (2007-2011) at all sites, approximately 26,260 harbour seals were counted in the UK: 80% in Scotland; 15% in England; 5% in Northern Ireland (Table 3). Including the 2,900 seals counted in the Republic of Ireland produces a total count of 29,167 harbour seals for the British Isles.

Not all individuals in the population are counted during surveys because at any one time a proportion will be at sea. The survey counts are normally presented as minimum estimates of population size. SMRU used flipper mounted satellite transmitters to track haulout behaviour during the moult and derived a multiplier to convert counts to total population size[1]. The result is similar to previously derived estimates and suggests that approximately 72% (95% CI 54% to 88%) of the population will be available to be counted during the normal survey window. This varies with the sex ratio of the population, but assuming an equal sex ratio the estimated total

[1] Mike Lonergan, Callan Duck, Simon Moss, Chris Morris & Dave Thompson (2012). Rescaling of aerial survey data with information from small numbers of telemetry tags to estimate the size of a declining harbour seal population. *Aquatic Conservation.* DOI: 10.1002/aqc.2277

population of harbour seals in the UK in 2010 was 36,500 (approximate 95% CI 29,900 – 48,650).

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 2011 count was 6% lower than 2010 but similar to the 2009 counts. The estimated pup production in the Wash in 2011 was 23% lower than in 2010 and was therefore very close to the 2009 estimate (SCOS BP 12/03).

The most recent counts of harbour seals by region are given in Table 3 and Figure 1. These are minimum estimates of the British harbour seal population. Results of surveys conducted in 2011 are described in more detail in SCOS-BP 12/3 and 12/04. 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.

2. Population trends

As reported in SCOS 2008 to 2011 there have been general declines in counts of harbour seals in several regions around Scotland.

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 and was only marginally lower than the highest count of 2,820 in 1996. This sudden apparent increase more than compensates for the gradual decline of 35% between 1996 and 2008. Although there is no specific information on vital rates in this population and there is substantial variability in counts, the recent large increase suggests that there may have been an influx of seals from other areas. The status of the harbour seal population in the Outer Hebrides is unclear. Until further information is available, SCOS recommends that the conservation in the Outer Hebrides order remain in place.

In 2011, the Inner Moray Firth (Ardersier to Loch Fleet) count was 674, 30.0% lower than the high August 2010 count (975). This count was still 20% higher than the mean of counts for 2007-2009 suggesting that the long term decline in the Moray Firth population may have been halted.

The Firth of Tay count in 2011 was the lowest ever recorded (77 seals) and was 38% lower than the 2010 count. This SAC population has declined at an average rate of 20% p.a. since 2002 with the 2011 count, 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 cause of the additional mortality is removed (SCOS-BP 12/04).

A complete survey of Orkney in 2010 counted 6.2% fewer seals than during the previous complete count in 2008. These latest results suggest that the Orkney harbour seal population declined by 68% since the late 1990s and has been falling at an average rate >11% p.a. since 2001. The recent counts may indicate a slowing down of the rate of decline, with an average decrease of 3% pa over the last two years.

Survey results from 2008 confirmed that the North coast of Highland Region has declined by 35% since the 2005 survey and is approximately 60% lower than in 1997.

Only part of Strathclyde region was surveyed in 2009. Counts for that subsection were 15% higher than in 2007. A count of the entire Strathclyde region in 2007 was 25% lower than in 2000 but similar to counts in the mid-1990s. If the subsection counted in 2009 was representative, the overall Strathclyde population would have been intermediate between the 1990s and early 2000 counts.

Table 3. Counts of harbour seals by region

Harbour seal Management Area	**Recent count** (2007-2011)	**Previous count** (2000-2005)	**Earlier count** (1996-1997)
Shetland	**3,039**	**4,883**	**5,991**
	2009	2001	1997
Orkney	**2,687**	**7,752**	**8,523**
	2010	2001	1997
Highland	**112**	**174**	**265**
North coast	2008	2005	1997
Outer Hebrides	**2,739**	**2,067**	**2,820**
	2011	2003	1996
West Scotland, Highland	**4,696**	**4,665**	**3,160**
(Cape Wrath to Ardnamurchan Point)	2007, 2008	2005	1996, 1997
West Scotland, Strathclyde	**5,914**	**7,003**	**5,651**
(Ardnamurchan Point to Mull of Kintyre)	2007, 2009	2000, 2005	1996
South-west Scotland, Firth of Clyde	**811**	**581**	**923**
(Mull of Kintyre to Loch Ryan)	2007	2005	1996
South-west Scotland, Dumfries & Galloway (Loch Ryan to English Border at Carlisle)	**23** 2007	**42** 2005	**6** 1996
East Scotland, Firth of Forth	**148**	**280**	**116**
(Border to Fife Ness)	2007	2005	1997
East Scotland, east coast	**167**	**406**	**648**
Fife Ness to Fraserburgh	2007, 2011	2005	1997
East Scotland, Moray Firth (widest)	**954**	**959**	**1429**
Fraserburgh to Duncansby Head	2007, 2011	2005	1997
TOTAL SCOTLAND	**21,291**	**28,812**	**29,532**
	(2011)	(2005)	(1997)
Blakeney Point	**349**	**709**	**311**
The Wash	**2,894**	**1,946**	**2,461**
Donna Nook	**205**	**421**	**251**
Scroby Sands	**119**	**57**	**65**
		2004	
Other east coast sites	**436**	**153**	**137**
		1994-2003	1994 –1997
South and west England (estimated)	**20**	**20**	**15**
TOTAL ENGLAND	**4,023**	**3,306**	**3,240**
TOTAL BRITAIN	**25,314**	**32,118**	**32,772**
TOTAL NORTHERN IRELAND	**948**	**1,248**	
	2011	2002	
TOTAL BRITAIN & N. IRELAND	**26,262**	**33,366**	
TOTALREPUBLIC OF IRELAND	**2,905**	**2,905**	
	2003	2003	
TOTAL GREAT BRITAIN & IRELAND	**29,167**	**36,271**	

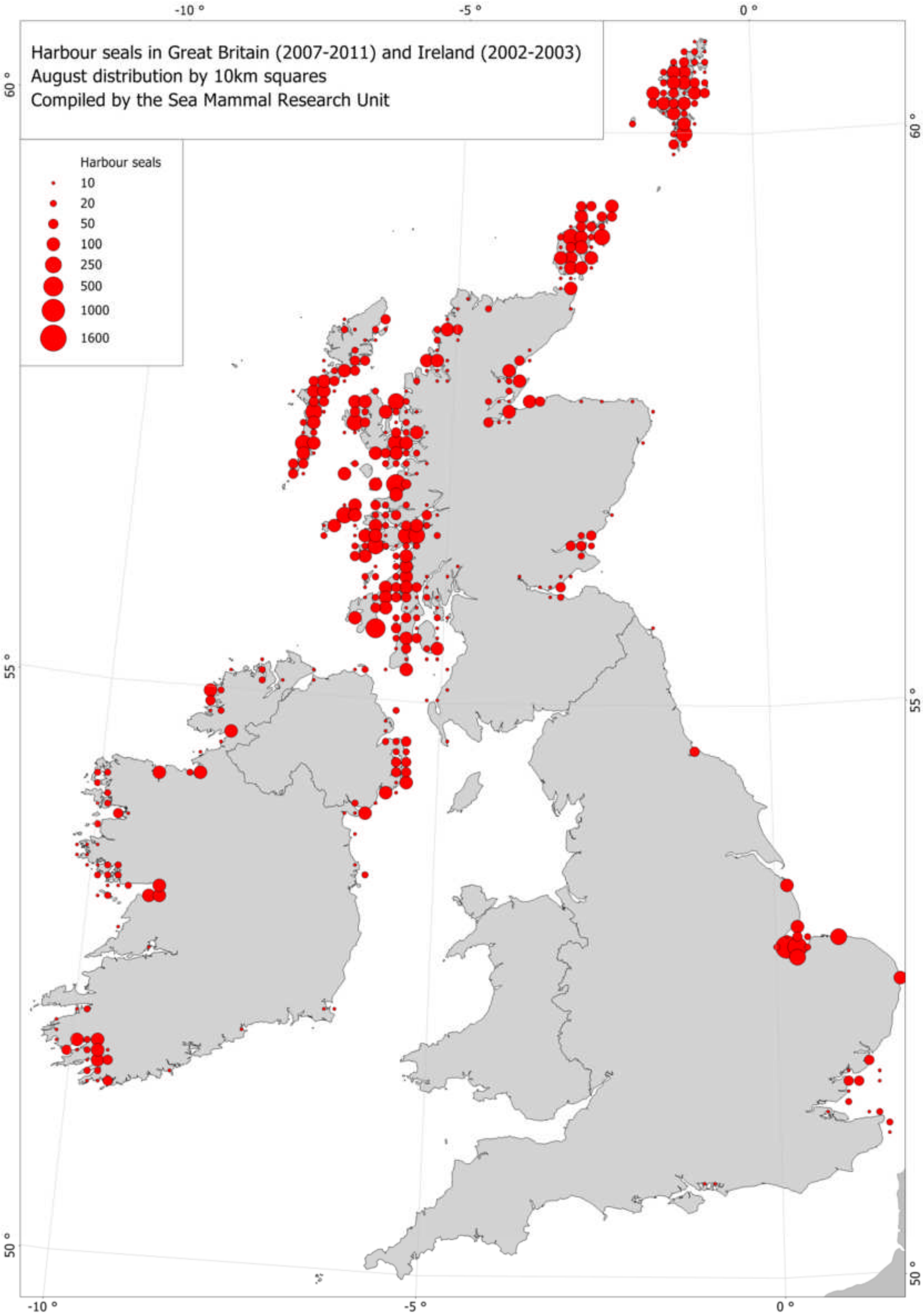

Fig. 1. The August distribution of harbour seals in Great Britain and Ireland, by 10km squares. These data are from surveys carried out between 2007 and 2011 in Great Britain and 2002-2003 in Ireland

Surveys in 2007 confirmed that the west coast of Highland Region has not shown any decline.

Overall, the combined count for the English East coast population (Donna Nook to Scroby Sands) in 2011 was 8% lower than the 2010 count. However, this was 26% higher than the mean of counts between 2004 and 2008. The 2011 total count was therefore close to the pre epidemic count in 2002 (SCOS-BP 12/3). The 2011 estimated peak pup count for the Wash was 23% lower than the 2010 estimate, and was therefore close to the 2009 count, which was 14% higher than the peak count in 2008. Despite these large increases, the English population has not kept pace with the rapid growth in the nearest European population in the Wadden Sea which increased by 9% between 2010 and 2011 and has grown by approximately 12% pa since the 2002 PDV epidemic.

2.1. Response to harbour seal declines

The widespread declines give clear cause for concern and have resulted in the implementation of area-specific Conservation Orders by the Scottish Government, providing harbour seals with year-round protection. A targeted research programme has been established including increased monitoring to confirm the magnitude and geographical extent of the declines and comparative studies of pup survival in areas of contrasting population dynamics.

In 2008, SCOS recommended that a programme of research be developed to address specific hypotheses about the causes of the decline and that SMRU should seek additional funds to support such a research programme. A summary of the issues to be addressed was discussed by SCOS in 2009. Briefly, the following questions were identified as the priorities for research. Current state of knowledge on each question is provided for each.

Is it likely that an artefact of the survey methodology or any of the following changes in the seals' behaviour or environment could account for the observed changes in counts without a population change?

1. Is reduced food availability causing any of the following effects? If so are they sufficient to account for the observed declines through:

   - Prey availability

     There is reason for concern that prey availability is limiting, as several of the key prey species are currently at low abundance levels. The North Sea sandeel stock is currently at reduced abundance compared to the 1990s [2], and was especially low in the years 2003 and 2004; sandeels are regarded to be an important diet component for harbour seals. Also, whiting, cod, and Norway pout have declined significantly since the 1980s/1990s [1]; these fish species are consumed by harbour seals especially in the northern North Sea including Shetland[3]. On the other hand, several prey species are increasing (e.g. herring, sprat, mackerel); these increases may not be sufficient to offset the decreases in other prey species, and the increases of sprat and juvenile herring are mainly in the southern North Sea[4].

[2] ICES (2011b). Report of the Working Group on the Assessment of Demersal Stocks in the North Sea and Skagerrak (WGNSSK). ICES CM 2011/ACOM:13
[3] Brown, E., Pierce, G.J., Hislop, J.R.G., Santos, M.B. (2001). Interannual variation in the summer diets of harbour seals *Phoca vitulina* at Mousa, Shetland. Journal of the Marine Biological Association of the UK 81: 325-337.
[4] ICES (2011a). Report of the Herring Assessment Working Group for the area South of 62°N (HAWG). ICES CM 2011/ACOM:06.

- Reduction in pup survival
  pup survival low in Orkney and west coast, but not different between areas.
- Reduction in adult survival
  Declines in both the Northern Isles and the Tay and Eden SAC populations are too steep to be due solely to pup mortality. Therefore in at least these areas reduced adult survival must be a factor.
- Reduction in fecundity
  No information
- *Reduction in growth rates*
  Examination of teeth from recent and pre 2003 samples showed no significant differences in growth patterns that might have been expected if food availability was adversely affecting UK harbour seals.
  .

2. Is the decline due to competition between harbour and grey seals?

- *Do grey and harbour seals compete for food?*
  A UK wide diet comparison is underway. Samples for both species have been collected throughout Scotland and along English east coast. Samples currently being analysed (SCOS-BP 12/08) and will be presented to SCOS 2014.
- *Do grey seals exclude harbour seals from certain habitats?*
  No information. Analysis of existing telemetry data may be useful, but limited simultaneous movement data is available
- *Do grey seals kill young harbour seals?*
  Some anecdotal information suggests this may occur in Orkney, the Moray Firth and East Anglia

3. Are any of the following direct mortality effects having a significant impact on the harbour seal population?

- Disease
  A major effect on UK harbour seal populations was documented in 1988 and 2002, but infectious disease is not apparently associated with recent declines.
- Biotoxins
  Results of monitoring suggest this may be a contributory factor around Scotland
- Pollution
  Not thought to be a major contributory factor
- Predation
  predation by killer whales (Orcinus orca) may be a contributory factor in Shetland
- By catch
  Little information, but this is not thought to be a major factor for harbour seals
- Deliberate killing
  Seals are killed to protect fisheries and fish farms. Little available information, but new Scottish licensing system should improve this. Data on seals killed under licence are available on the Marine Scotland web site at : www.scotland.gov.uk/Topics/marine/Licensing/SealLicensing

In response to the declines, SCOS recommended that monitoring surveys of the harbour seal populations should be given a high priority and that repeat surveys of Orkney and other regions would be desirable. Additional studies to obtain independent estimates of the proportions of the population ashore during surveys and any improvement in our knowledge of demographic parameters should be encouraged. In response, SMRU, with funding support from NERC, Scottish Government (Marine Scotland Science), Scottish Natural Heritage and Natural England, have conducted a research programme which includes:

1. thermal image surveys of harbour seal moulting populations in Shetland, Outer Hebrides, Strathclyde and repeat surveys in Orkney,
2. continuation of the annual fixed wing surveys of the English and Scottish east coast moulting populations,
3. continuation of the pup production surveys in the Moray Firth and East Anglian populations,
4. a satellite-telemetry based study of proportion of time seals spend hauled out during the moult in two populations with contrasting dynamics, i.e. Orkney and the west coast,
5. a telemetry based study of pup survival rates in two populations with contrasting dynamics, i.e. Orkney and the west coast.
6. continued investigations into disease, biotoxins and environmental factors affecting survival in harbour seals

Results from these studies were presented to SCOS in 2010 and 2011

In 2009 a previously unidentified source of anthropogenic mortality was identified in harbour and grey seals in Scotland. Throughout 2010 and 2011 similar severely damaged seal carcasses (named ‘corkscrew’ seal injuries) were reported from various locations around the UK. In Scotland, similarly damaged seals were found on beaches on the east coast (Aberdeen, Montrose, St Andrews Bay, Tay and Eden Estuaries and Firth of Forth), in Orkney and at Ardrossan. In England a similar but more localised and intensive event occurred in North Norfolk, centred on the Blakeney Point nature reserve. Interestingly there have been no reports of similar deaths since August 2010 in East Anglia. Small numbers were also reported from Northumberland. Similar corkscrew seals were reported within and around Strangford Lough In Northern Ireland and in south west Wales . In 2012 to date there have been reports of similar deaths in harbour seals from Orkney, the Firth of Forth and the Tay and Eden estuaries. Re-examination of historical records indicates that these types of injuries have occurred since 1983 in Orkney.

All the seals had a characteristic wound consisting of a single smooth edged cut that starts at the head and spirals around the body. In most cases the resulting spiral strip of skin and blubber was detached from the underlying tissue. In each case examined so far the wound would have been fatal. The extremely neat edge to the wound strongly suggests the effects of a blade with a smooth edge applied with considerable force, while the spiral shape is consistent with rotation about the longitudinal axis of the animal. The injuries are consistent with the seals being drawn through a ducted propeller such as a Kort nozzle or some types of Azimuth thrusters. Such systems are common to a wide range of ships including tugs, self-propelled barges and rigs, various types of offshore support vessels and research boats. All the other explanations of the injuries that have been proposed, including suggested Greenland shark predation, are difficult to reconcile with the observations and, based on the evidence to date, seem very unlikely to have been the cause of these mortalities[5]. A detailed description of the mortalities is presented in SCOS BP 11/7 (available from the SMRU web site (http://www.smru.st-and.ac.uk/documents/366.pdf). The population consequences of these mortalities are unknown, but at a local level the numbers of pregnant adult females lost from the Tay population is clearly unsustainable. An analysis of the likely future status of the Tay/Eden population is presented in SCOS-BP 12/04.

[5] Steve Bexton, Dave Thompson, Andrew Brownlow, Jason Barley, Ryan Milne and Cornelia Bidewell (2012) Unusual Mortality of Pinnipeds in the United Kingdom Associated with Helical (Corkscrew) Injuries of Anthropogenic Origin. *Aquatic Mammals* 2012, *38*(3), 229-240, DOI 10.1578/AM.38.3.2012.229

2.2. UK harbour seal population in a European context

The UK harbour seal population represents approximately 30% of the eastern Atlantic sub-species of harbour seal (Table 4). The declines in Scotland and low rates of increase in the English populations mean that the relative importance of the UK population will probably decline.

Table 4. Sizes 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 information 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	**21,100**		
England	**4,000**	2011	Increasing [3]
Northern Ireland	**950**	2011	Decrease since '70s
UK	**26,300**		
Ireland	2,900	2003	Unknown
Wadden Sea-Germany	13,200	2011	Increasing after 2002 epidemic
Wadden Sea-NL	7,800	2011	Increasing after 2002 epidemic
Wadden Sea-Denmark	3,100	2011	Increasing after 2002 epidemic
Lijmfjorden-Denmark	1,050	2008	Recent decline [3]
Kattegat/Skagerrak	11,700	2007	Recent decline[3]
West Baltic	750	2008	Increasing
East Baltic	600	2008	Increasing
Norway	6,700	2006	Declining
Iceland	12,000	2006	Declining
Barents Sea	700	2008	Unknown
Europe excluding UK	**60,500**		
Total	**86,800**		

[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: www.smru.st-and.ac.uk; 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, & Sunnset BH. (eds). Havforskningsrapporten 2011. Fisken og havet, 2011(1).;
Härkönen,H. & 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,. & Härkönen T. 2010. Status of the harbour seal (Phoca vitulina) in Southern Scandinavia. NAMMCO Sci Publ 8: 77-94.

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?

1. Grey seals

Within Europe there are two apparently reproductively isolated populations, 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 reproductively isolated at least since the Last Glacial Maximum[6,7]. The vast majority (90%) of European grey seals breeding outside the Baltic breed around Britain. On the basis of genetic differences there appears to be a degree of reproductive isolation between grey seals that breed in the south-west (Devon, Cornwall and Wales) and those breeding around Scotland[8] and within Scotland, there are significant differences between grey seals breeding on the Isle of May and on North Rona[9]. 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[10].

Since 2003, a spatially-explicit model has been used to estimate the British grey seal population from geographically structured pup production estimates. A preliminary application of this model (SCOS-BP 03/4) 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 & 10/2).

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[11]. 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.

A NERC funded project to continue and extend the photo identification work began in 2009. A recognition system for pelage developed for identifying seals from head patterns has been modified to identify seals from pelage patterns on the flank, neck chest and abdomen. The catalogue now contains around 19,000 distinct IDs. The current project is focussing on the breeding season photographs from North Rona, a re-analysis of movement patterns outside the

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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 pp 1787-1796

7 Graves, J.A., Helyar, A., Biuw, M., Jüssi, M., Jüssi, I. & Karlsson, O. (2008) Analysis of microsatellite and mitochondrial DNA in grey seals from 3 breeding areas in the Baltic Sea. *Conservation Genetics.* **10**(1); pp. 59-68.

8 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. 293-296

9 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.

10 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-Revue Canadienne De Zoologie* 89(6): 490-497.

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

breeding season based on surveys conducted in the 1990s and an assessment of the consistency/identifiability of patterns from weaning through to adult pelage (SCOS-BP 12/06).

Pelage pattern in juvenile female grey seals is known to change in the first few years of life. However, the study provides evidence to suggest that despite that change, the stability of pelage patterns from weaning through to adulthood is sufficient to allow the use of automated software to make matches. This provides an opportunity for early survival and recruitment studies (SCOS-BP 12/08).

At a finer scale, i.e. within these sub-populations, there may be substantial movement or recruitment of breeding females to colonies other than their natal sites. This is thought to be the explanation for the rapid initial growth of colonies in the North Sea and at specific sites in the Hebrides and Orkney. In this respect, the 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. This North Sea group is thought to show a degree of reproductive isolation from those breeding in Devon, Cornwall and the Scilly Isles.

1.1. 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. 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 independent population estimate (SCOS-BP 10/4) indicate that the density dependent effects are operating through reduced pup survival (SCOS-BP 10/2 & 11/2).

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. 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). The age structured population model has so far been fitted using the fixed sex ratio of 1:0.73. As part of the investigation into the effects of changing the priors a model is currently being run with a prior distribution for sex ratio.

1.2. 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].

2. Harbour seals

Our knowledge of UK harbour seal demographic parameters is severely limited. The absence of historical information from large samples of dead seals, the absence of long time series of pup production estimates or even total population estimates at fine enough temporal resolution means that we do not currently have information to allow these parameters to be estimated with reasonable confidence. Because of this lack of knowledge all inferences on dynamics rely solely on count data. Information on vital rates would improve our ability to provide advice on population status.

Samples from seals in Northern Ireland, the west and east coasts of Scotland, the east coast of England, Dutch and German Wadden Sea, Kattegat/Skagerrak, Norway, Baltic Sea and Iceland have been subjected to genetic analysis. This analysis suggested that there may be significant genetic differentiation between harbour seal populations in European waters[13],[14]. The Irish-Scottish, the English east coast and the Wadden Sea harbour seals were identified as distinct population units. Further analysis of genetic data for populations within Scotland is still underway. There is probably little movement of breeding animals between these populations although satellite telemetry reveals some interchange between the Wadden Sea and the English east coast populations outside the breeding season. Within the Ireland-Scotland population there is probably occasional movement of animals between regions, but there is no evidence from satellite telemetry of any long-range movements (for example, between the east and west coasts of Scotland) comparable to those observed in grey seals.

Satellite tracking of pups showed that some dispersed widely from their natal sites. Orkney pups dispersed to Shetland, the Outer Hebrides and down the east coast as far as the Firth of Tay. Lismore pups spread throughout the Inner and Outer Hebrides and Northern Ireland. There was some indication that pups which moved long distances during the first few weeks after weaning did not survive. However, over the course of the study several pups appeared to establish effective foraging patterns in locations remote from their natal sites

In other European populations there is also little information on population scale movements. Studies of the movements of branded seals in the Kattegat/Skagerrak[15] indicate that there is only limited movement within the western Scandinavia population. However, in both 1988 and 2002 phocine distemper spread rapidly among European harbour seal populations, suggesting that substantial movement of individuals can occur, although the genetic studies suggest these movements do not result in large numbers of seals reproducing in locations they visit

[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.

[13] 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.

[14] Stanley, H. F., S. Casey, et al. (1996). "Worldwide patterns mitrochondrial DNA differentiation in the harbour seal (Phoca vitulina)." *Molecular Biological Evolution* **13**(2): 368-382.

[15] Härkönen, T. & Harding, K.C. (2001) Spatial structure of harbour seal populations and the implications thereof. *Canadian Journal of Zoology*, 79, 2115-2127.

temporarily. In addition grey seals are potential carriers of PDV and could therefore also influence the spread.

2.1. 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. Some age structure data were available from seals found dead during the PDV epidemics in 1988 and 2002. However, these were clearly biased samples and could not be used to generate population age structures.

Information on age and length of UK harbour seals are available from live captured seals and from dead seals sampled during the 1988 PDV epidemic. Results from live captures are presented in SCOS-BP 12/11.Within regions the sample sizes are relatively small and unbalanced reducing the scope for testing for differences. Briefly, there were no significant spatial differences in the age-length data obtained since 2003 and no temporal differences with the exception that the males in the Moray Firth had a significantly shorter asymptotic length (~ 6cm) compared to males captured in the early 1990s. This difference is difficult to interpret because of possible biases in the sampling strategy.

The age distributions of animals captured live in the Moray Firth between 1989 and 1995 were different to those of animals captured throughout the UK between 2003 and 2011. Those in the Moray Firth were significantly younger than those captured since 2003. Although the reason for this is not clear and although capture bias may certainly be responsible, it may also suggest a difference in the dynamics of this population during the period of sampling.

In the absence of consistent long time series of pup production or any systematic sampling of the population for age data, we are unable to define the age structure of the UK harbour seal population. With a sufficiently long time series of both pup production estimates and overall population indices (moult counts) the harbour seal population modelling approach under development at SMRU will be capable of generating age structures for the female component of the harbour seal population. Methods for estimating pup production from sparse survey data are being developed and a series of repeat surveys during the breeding seasons in the Wash and Moray Firth have been carried out to enable SMRU to estimate pup production and assess the errors in the developing time series of pup production estimates..

2.2. Survival and fecundity rates

SMRU have previously reported on a comparative study of survival rates of harbour seal pups in the declining Orkney and apparently stable West Coast populations. Results suggested that both populations have similar but high mortality rates and that differential pup mortality is unlikely to be responsible for the observed demographic patterns[16].

Aberdeen University have established a long term monitoring project at a new and growing breeding site in Loch Fleet. This study has used photo i.d. methods in a mark recapture framework to generate both survival and fecundity estimates. In addition the study is providing information on site fidelity and timing of breeding. Details of the study were presented in SCOS-BP 11/5

Recent large inter-annual fluctuations in pup counts in The Wash population have not been

[16] Hanson,N., Thompson,D., Duck,C.D., Moss,S. & Lonergan,M. (in prep) Assessing pup mortality as a cause for rapid decline in a harbour seal (*Phoca vitulina*) population.

matched by large fluctuations in the moult population counts (SCOS-BP 12/03). The simplest explanations for such differences are that either there was a large and temporary influx of breeding females into the Wash in 2010 or that there have been large variations in fecundity.

2.3 Current work

Work is currently underway to develop recommendations for spatial management units and to connect these to population structure. This is partly built from studies of movements and habitat use (SCOS-BP 05/3 and 05/5). Refined population scale usage maps have been developed and are presented in SCOS-BP 12/05 and Figures 2 & 3.

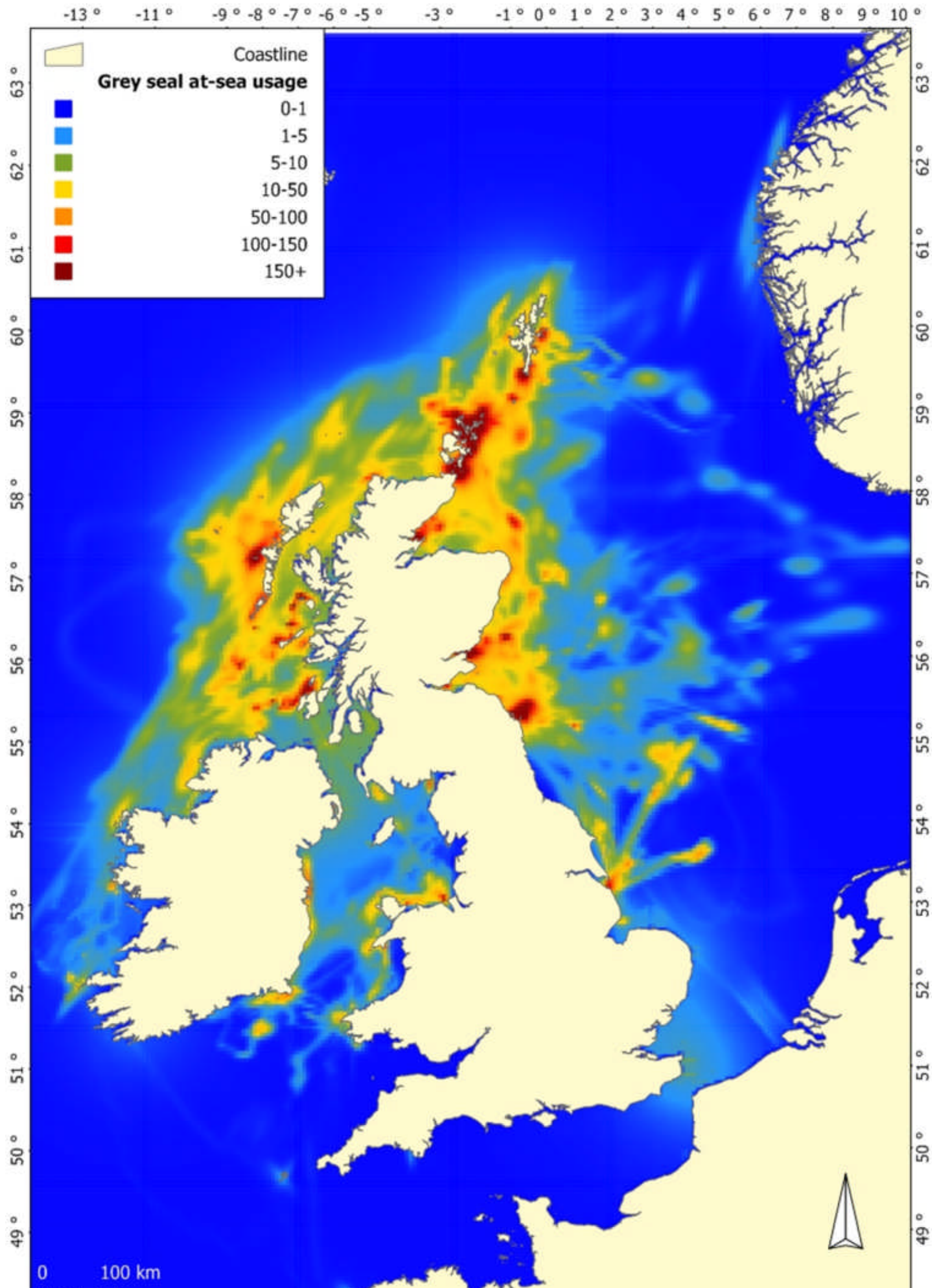


Fig. 2. Estimated grey seal total (at-sea & hauled-out) usage around the UK. White contours show standard deviation from mean usage as a measure of uncertainty.

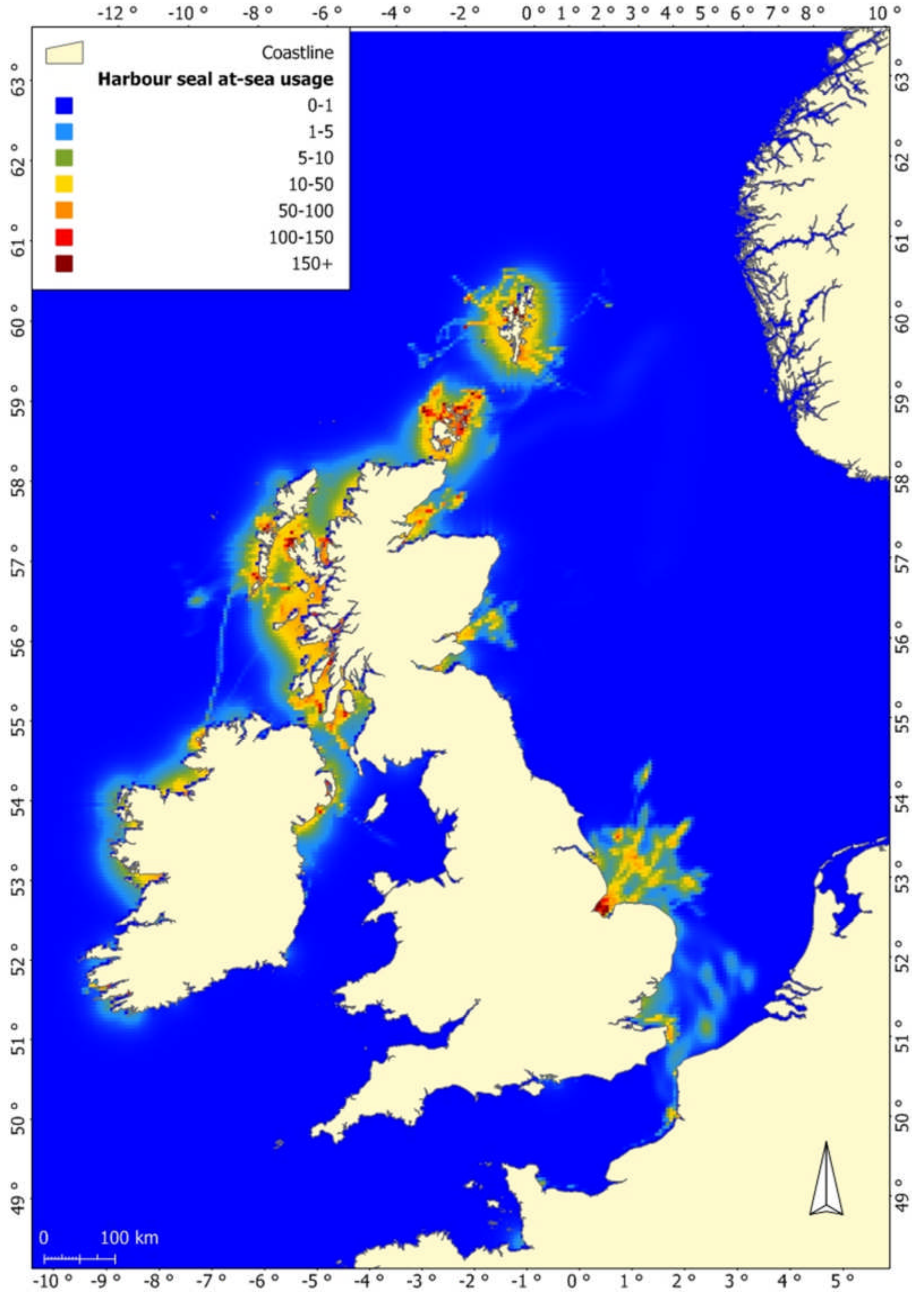


Fig. 3. Estimated harbour seal total (at-sea & hauled-out) usage around the UK. White contours show standard deviation from mean usage as a measure of uncertainty.

Defining optimal management areas for UK seals requires an arrangement of relatively isolated groups of colonies. The motivation behind this requirement is that management actions taken in one unit should have minimal impact on the others. Clustering algorithms have been developed to subdivide grey seal breeding colonies into maximally isolated groups according to at-sea distance (SCOS-BP 06/5) and a method for optimal design of marine SACs based on at sea location data was presented in 2007 (SCOS-BP 07/8)

Spatial population structure is also an important element in the development of a network of haulout sites to be designated for protection under the Marine (Scotland) Act 2010. SCOS-BP 12/07 describes the process used to identify the appropriate set of haulouts depending on the particular criteria applied and to define the spatial extent of each protected site.

SCOS 2009 recommended additional effort to improve the estimates of harbour seal population size including improved estimates of the proportion hauled out during the moult, inclusion of high resolution digital imagery of all seals during thermal image surveys and the acquisition and use of new, reliable thermal imaging equipment. In addition, complementary modelling activities to support the collection of data should be given high priority. A telemetry study to address the question of haulout proportion was carried out in 2009. The proportion of time spent hauled out did not differ between seals tagged in the stable west coast and declining Orkney populations and the overall proportion of time spent hauled out during the moult was similar to previous estimates. A full analysis of the results has been submitted for publication and is appended as SCOS BP 11/8. Digital photography has been included throughout the harbour seal surveys to improve and confirm species identification. A harbour seal population model has been developed and submitted for publication.

Harbour Seal Population

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

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. Figure 4 below shows the population trends in the different survey/management regions around Scotland. The latest survey results confirm that:

- the Orkney harbour seal population declined by approximately 65% since the late 1990s. Including the 2010 counts, the population has been falling at an average rate of approximately 11% p.a. since 2001. However, the 2010 count was similar to the 2008 count and may be an early indication that the rapid declines are slowing. Additional data will be required to test this.
- the Shetland harbour seal population declined by approximately 50% since the late 1990s However, the Shetland survey in 2009 produce an identical count to that in 2006. Again, this may be an early indication that the rapid declines are slowing. Additional data will be required to test this.

- the Outer Hebrides harbour seal population had apparently shown a sustained but gradual decline of around 3% pa since 1996 and had declined by approximately 35% by 2008. However, the 2011 count was >50% higher than the previous count in 2008 suggesting overall there has been little change. The recent fluctuation may indicate large scale movement into the area and requires further investigation.
- the Strathclyde harbour seal population has shown wide fluctuations but recent surveys indicate little overall change since the mid 1990s.
- the counts in the Moray Firth increased by more than 40% between 2009 and 2010, but then decreased by 30% in 2011. This count was still 20% higher than the mean of counts for 2007-2009. This oscillation followed a period of 5 years during which the counts have remained approximately steady after a rapid decline of approximately 50% in the previous 10 years. This suggests that the long term decline in the Moray Firth population may have been halted (Figure 5).
- the population in the Firth of Tay has declined dramatically, by approximately 89% since 2000, and has declined at an average rate of 20% p.a. over the last 10 years (Figure 6).
- the harbour seal populations of the west coast of Highland Region has not shown any significant decline since the late 1990s.
- the English East coast population declined after the 2002 PDV epidemic but the count increased by 30% in 2009 and 9% in 2010. The 2011 count was 8% lower than the 2010 count but is still close to the pre epidemic count in 2001.
- the nearest European population, in the Wadden Sea, has continue to grow at approximately 12% pa since the 2002 PDV epidemic. 2011 counts were 9% higher than 2010 counts.

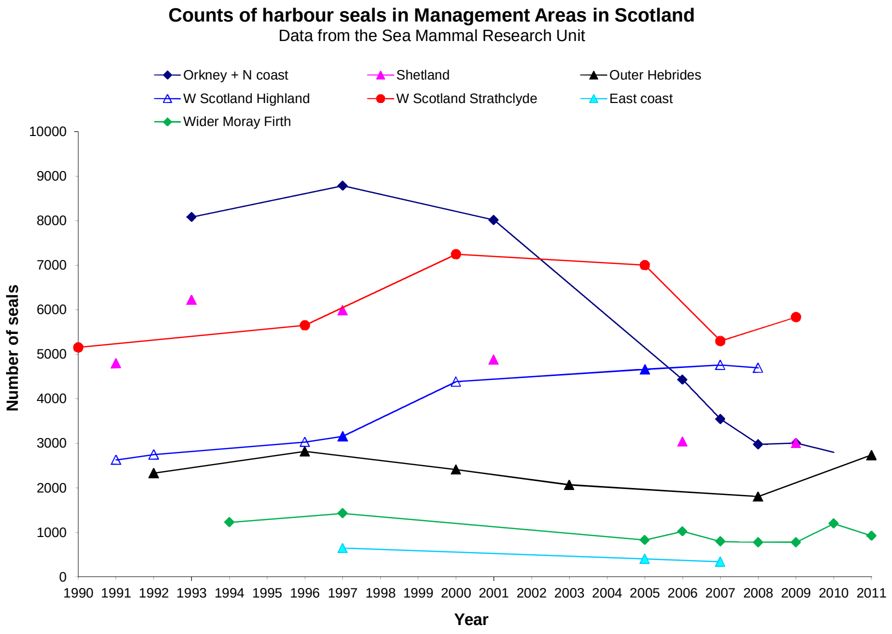


Fig. 4. Trends in moult counts of harbour seals around Scotland.

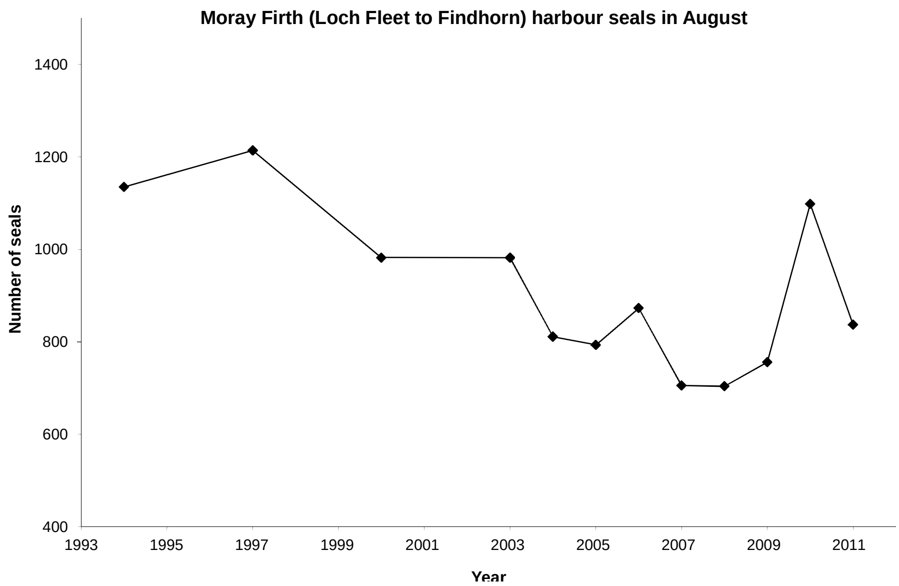


Fig. 5. Trends in moult counts of harbour seals in the Moray Firth.

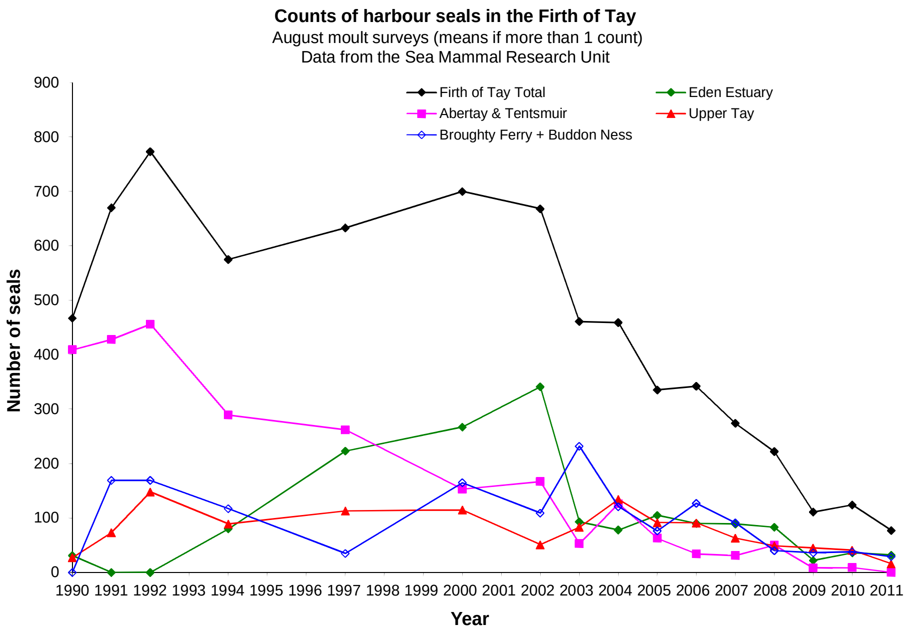


Fig. 6. Trends in moult counts of harbour seals in the Firth of Tay and Eden S.A.C.

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?

The dramatic decline in the population of harbour seals in the Firth of Tay and Eden Estuary SAC is continuing and is a clear cause for concern. A detailed analysis of the current status and likely trends under a set of different scenarios is presented in SCOS-BP 12/04. 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. While the cause of the decline is unknown, it must be reducing adult survival. Recovery of the population to the abundance when the SAC was designated is likely to take at least 40 years, even if its cause is immediately identified and rectified. Partial removal of the cause will have limited benefits. There are unlikely to be any long-term benefits from introducing or reintroducing additional individuals while the problem persists.

In 2010 SCOS expressed its concern over the emergence of a new source of anthropogenic mortalities, primarily of pregnant female harbour seals close to the SAC. SCOS consider that without urgent mitigation the population will continue to declines. 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 11/7. To date no effective mitigation measures have been identified although potential changes to shipping operations in the SAC are under discussion. This situation remains unchanged and dead seals have been reported throughout 2011 and early 2012. See Question 13 below for more detail.

Conservation orders are currently in place for the Outer Hebrides, Northern Isles and down the east coast as far as the border. In 2009 SCOS recommended additional data collection and monitoring to further investigate the requirement for extending these orders.

SCOS 2010 noted that the Outer Hebridean population showed a consistent gradual decline of approximately 3.5% p.a. that has been maintained since the mid-1990s. Following the same precautionary principle as earlier, 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 Strathclyde 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 actions are likely to benefit harbour seal populations but consider that the situation in the Tay and Eden SAC is a serious concern and that further investigation of the causes should be a priority for research

5. What is the latest understanding of the causes of the recent decline in harbour seals?

In response to concerns over the apparent continuing decline in several harbour seal populations Marine Scotland commissioned SMRU to organise and host a workshop on the reasons for the decline. A broad based group of UK and international researchers and population managers were invited to a workshop held immediately before the SCOS 2012 meeting. The final report of this workshop will be available for SCOS 2013.

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?

In areas where seal populations are declining, they can be expected to continue to decline unless the cause of the decline is a density dependent reduction on survival or fecundity. A detailed analysis of the likely trends in the Tay and Eden SAC is presented in SCOS-BP 12/04. This is the area with the most rapid and prolonged decline in Scotland, having experienced a 90% decline since 2000. The prognosis is bad. 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. While the cause of the decline is unknown, it must be reducing adult survival. Recovery of the population to the abundance when the SAC was designated is likely to take at least 40 years, even if its cause is immediately identified and rectified.

Seal Diet

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

In 2010, a project funded by the Scottish Government was initiated to provide a comprehensive assessment of regional and seasonal variation in harbour seal diet composition and prey consumption through the analysis of prey remains (fish otoliths and cephalopod beaks) recovered from scats collected from haul-out sites throughout Scotland. The project also includes estimation of the diet of grey seals in key regions/seasons to assess the potential for competition for food between these two species. Grey seal diet will also be compared with the results from studies in 1985 and 2002 to investigate changes on an approximately decadal time scale. Details of the progress are presented in SCOS-BP 12/08.

In total, 8,354 scats have been collected across Scotland and England. Sample sizes vary considerably among regions and seasons. Few scats were collected in Orkney and Shetland in autumn and winter 2010 so additional sampling was carried out in 2011.

Work has focussed initially on grey seal scats from Scotland, 83% of which have been processed and hard prey remains recovered. Just over half of these prey remains have been identified and about 10% have been graded and measured and are ready for analysis.

In total, 6,613 scats have been subsampled for molecular analysis (species/sex identification). To date 678 have been analysed to give species: 164 grey seals, 464 harbour seals and 50 undetermined. Sex identification of seal faeces at west coast SACs is currently being conducted.

Experiments to estimate digestion coefficients, number correction factors and passage rates of fish otoliths and cephalopod beaks for harbour seals are ongoing. So far 59 feeding trials have been conducted using 4 seals and 10 prey species.

Estimates of grey seal diet composition and prey consumption are expected to be completed in September 2013. Harbour seal digestion experiment results are expected by spring 2013. Diet estimates for harbour seals are expected to be completed in December 2013.

Seals and Salmon Netting Stations

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

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. Ten grey seals and 4 harbour seals were identified on at least one occasion, and 2 grey seals made up 63% of the visits to the study area when individuals were identified. This lends support to the suggestion that few seals are involved in predation at nets and that such specialists are responsible for most seal activity and presumably predation events at netting stations.

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. Overall grey seal activity at both Moray Firth and Montrose sites peaked in 2010 coinciding with an increase in the numbers of grilse returning to rivers in that year. Harbour seal activity at nets was generally low, especially at Moray Firth sites. A briefing paper giving full details of the observation and diet study will be presented to SCOS 2013.

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. The proportion of seals that contained salmonid prey and the prevalence of other prey were consistent with results from previous seal diet studies from salmon bag-nets in Scotland.

Available mitigation methods that provide alternatives to shooting include use of Acoustic Deterrent Devices (ADD). During 2009 and 2010 an ADD was tested at a fixed salmon net. 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 briefing paper giving full details of the ADD studies will be presented to SCOS 2013.

Seals and Fish Farms

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

This has been recognised as a problem for some time in terms of the damage caused to cages and fish, but also in terms of secondary effects because of salmon escaping from cages and mixing with local wild populations. More recently, however, the potential effects of methods used to control seals around fin fish farms, involving acoustic deterrent devices (ADDs) and/or shooting seals in the vicinity of farm cages, have been increasingly viewed as a concern. This is partly because of potential effects of ADDs on other marine mammals and partly because the decline of harbour seals has focussed attention on ways in which it may be possible to reduce shooting of seals.

SMRU have recently completed a study funded by the Scottish Aquaculture Research Forum (S.A.R.F)[17] to investigate the management of interactions between seals and salmon farms and to specifically investigate the extent to which the Acoustic Deterrent Devices (ADDs) used in Scottish fish farms exclude or affect the distribution of cetaceans, how effective they are in preventing seals from damaging fish pens and damaging farmed fish or allowing fish to escape.

Long term seal survey data and fish farm distribution were compared to investigate the possibility that fish farms were implicated in the observed population declines. In all regions except Strathclyde the number of seals counted at haul out sites close to fish farm sites as a proportion of the total number counted in each region remained effectively constant suggesting that there have not been disproportionate declines at haul out sites closest to farm sites. The relative decline in seal numbers close to fish farm sites in Strathclyde requires further investigation.

A combined observation, video monitoring and photo i.d. study was carried out at several farms. Preliminary results indicate that photo-identification is possible at fish farm sites and can be used to explore the behaviour of individual animals. Trials of a novel seal deterrence system based on an acoustic signal specifically designed to trigger a seal's startle response is currently being tested and preliminary results suggest that it may be effective in deterring seals at salmon farms.

SCOS believe that increased or improved application of standard husbandry techniques 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 field in sea water funded by S.A.R.F. Preliminary trials with both grey

[17] Northridge, *et.al*. 2010. Assessment of the impacts and utility of acoustic deterrent devices. Final Report to the Scottish Aquaculture Research Forum, SARF044. 34pp.
copies available at : www.sarf.org.uk/Project Final Reports/SARF044 - Final Report.pdf

and harbour seals indicate that they are sensitive to and can be deterred by these low voltage pulsed fields[18]. Initial results suggest that this method may provide an additional seal deterrent capable of preventing seals from touching the netting of marine fish cages.

Seals and Marine Renewables

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

The only direct information on interactions between seals and marine renewables is from 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 early deployment stage of SeaGen, a large twin rotor tidal turbine.

Telemetry data shows harbour seals continue to use Strangford Narrows and SeaGen is not a barrier to their passage. Analysis of all of the tagged seals showed no statistically significant change during operation and non-operation of SeaGen however, this was likely due to high inter-individual variation in transit rates. Further investigation of the effect of operation and non-operation showed that seals which transited the Narrows regularly 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 visual survey data has shown that there has been no change in relative abundance of harbour seals associated with turbine operation, though there is evidence for a small scale (few hundred metres) redistribution of harbour seals during operation. No change or redistribution for either grey seals or harbour porpoises was detected although sightings rates were much lower for these and power to detect change was low

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 with high noise levels during pile driving operations[19]. Although position accuracies made comparisons difficult, seals were seen foraging within the site during the operational phase.

Both grey and harbour seals have continued to use the Scroby Sands haulout site (off East Anglia) (SCOS BP 11/3) despite the construction of a large wind turbine array within a few kilometers of the site.

Using a combination of funding from Marine Scotland and SNH, SMRU are conducting a large scale telemetry programme to study the movements of grey and harbour seals in

[18] Ryan Milne, Jeff Lines, Simon Moss & David Thompson (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/

[19] Tougaard, J., O. D. Henriksen, *et al.* (2009). "Underwater noise from three types of offshore wind turbines: Estimation of impact zones for harbor porpoises and harbor seals." *Journal of the Acoustical Society of America* 125(6): 3766-3773.

relation to high tidal energy sites. Preliminary reports of the results from grey seal pups are presented in SCOS-BP 12/09 and for harbour seals in The Pentland Firth and Kylerhea in SCOS-BP 12/10. In addition, a DECC funded study of the movement patterns of harbour seals in relation to active operational wind farms and pile driving activity is underway in the Wash and Thames estuaries. Details of results from these studies will be presented to SCOS 2013.

Seal Licensing and PBRs

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

At present SCOS does not consider that there is an appropriate alternative to the PBR for use in relation to the seal licence system. Although PBR is widely used, it is recognised that it may not be the best method for managing seal populations. A discussion of the relative merits of different methods has been published and is appended to the 2011 report. However, the information required for assessing carrying capacity or determining appropriate alternative management targets is not yet available and in the short term a conservative version of the PBR should continue to be used for managing anthropogenic impacts on Scottish seal populations.

12. 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?

Information on numbers of seals shot under licence is available for Scotland from 2011 onwards (*www.scotland.gov.uk/Topics/marine/Licensing/SealLicensing*). 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. SCOS are unaware of any reliable estimates of the numbers of seals harmed or killed during any other offshore industrial activities.

Recent observations of seals thought to be killed by ships propellers indicate that there may be a potentially large incidental mortality of seals during shipping activity. The scale and extent of this mortality is discussed in answer to Question 13 below.

Unusual Seal Mortalities

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

A description of the initial investigation into the occurrences of seals with unusual spiral lesions was presented in SCOS BP 11/7. An updated report is being prepared for Scottish Government and will be presented as a briefing paper to SCOS 2013. Table 5 shows the number of severely damaged seal carcasses washed ashore around Scotland and reported to the Scottish Marine Animal Strandings Scheme (SMASS) or SMRU. A total of 48 grey and 32 harbour seals have been found in Scotland by the end of 2012. A total of 38 grey and harbour seals have been found along the North Norfolk coast between December 2009 and September 2010. No further carcasses were seen in Norfolk but carcasses continue to appear along the Scottish east coast. The seals have all apparently been killed by a characteristic wound consisting of a single smooth edged cut that starts at the head and spirals around the body. In most cases the resulting spiral strip of skin and blubber is detached from the underlying tissue. The wound is clearly the cause of death in each case examined so far[20]. Similar injuries have now been described on seals in Strangford Lough in Northern Ireland, at two locations on the Scottish west coast, in Orkney and at Aberdeen and Montrose. Re-examination of pathology reports indicates that the mechanism is the same in each case and that these wounds have been seen on seals as far back as 1985

Table 5. Numbers of seals with corkscrew wounds reported 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	

The extremely neat edge to the spiral wound strongly indicates a cut made by a rotating blade within a channel or cowling of some sort or by the seal rotating past some form of static blade. The presence of additional facial wounds that match the shape of propeller rope cutter blades strongly suggests that the wounds were caused by some form of ducted propellers such as Kort drives or some types of azimuth thruster. SMRU are currently investigating the mechanism of injury to narrow down the range of potential vessels.

The relatively small numbers of seals found so far are unlikely to have a significant impact on large seal populations. However, in St. Andrews Bay and the Firth of Tay the harbour seal population has undergone a significant decline in the past decade. In 2010 the highest count of harbour seal pups in the Tay and Eden estuaries was 11 and in 2011 the highest count was 7. In the same years 6 and 4 pregnant adult females were found dead. If these numbers represent the size of the breeding population it is clear that the current level of observed mortality could wipe out the breeding population in only

[20] Steve Bexton, Dave Thompson, Andrew Brownlow, Jason Barley, Ryan Milne and Cornelia Bidewell (2012) Unusual Mortality of Pinnipeds in the United Kingdom Associated with Helical (Corkscrew) Injuries of Anthropogenic Origin. *Aquatic Mammals* 2012, *38*(3), 229-240, DOI 10.1578/AM.38.3.2012.229

one or two years. We do not know if this mortality is a local inshore problem or a more widespread problem that has come to light because the recent mortalities have occurred close to shore.

In response, SMRU have begun to investigate potential causal mechanisms in collaboration with the RSPCA and Scottish Marine Mammal Stranding Scheme, with support from Marine Scotland, Scottish Natural Heritage and Natural England. Due to the seriousness of these mortalities, preliminary results and an interim progress report were circulated to SCOS in October 2010 and a modified version was presented as SCOS BP 11/7.

SCOS recommends that experimental studies be conducted to test the ship propeller strike hypothesis. Where possible these experiments should be conducted using seal carcasses and appropriate propeller mechanisms.

Defra QUESTIONS

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

See answer to Scottish Government Question 1 above.

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

See answer to Scottish Government Question 2 above. As part of the UK wide study, samples from seals in the Wash, Thames and on the south coast have been included in the analysis.

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

See answer to Scottish Government Question 2 above.

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

A study of the geographical and seasonal patterns in the diets of grey and harbour seals on the east coast of England is being carried out in conjunction with a wider study around the entire Scottish coast. A description of the progress on this project is given in answer to the Scottish Government Question 7 above and in more detail in SCOS-BP 12/08.

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?

There have been no specific developments and there is therefore no new information to alter the answer given in SCOS Advice in previous years.

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?

Substantial data sets on movements and foraging behaviour have been collected from both grey and common seals over the past 10 years. When combined with aerial survey information on distribution of haulout sites and relative abundance of each species at these sites, the tracking data allows us to develop population scale habitat usage maps for the entire UK. A revised model for estimating seal population distributions at sea incorporating population survey data and fine scale telemetry tracking data has been developed and can be used to provide accurate habitat usage maps. A detailed description of habitat preference modelling based on grey seals in the North Sea has been published[21] and an updated analysis of the distribution/habitat usage for both species is given in SCOS-BP 12/05.

In spring 2012 a large scale study of movements of harbour seals in the Wash and the Thames was initiated. 25 seals were tagged with GPS/GSM phone tags in the Wash and 10 in the Thames. Results from this study will be available for SCOS 2013.

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. Individuals of both species show behaviour indicating a mixture of periods of wide ranging foraging movements with little or no concentration on particular areas and regular repeated foraging in discrete patches. Overall, the intensity of habitat usage is assumed to indicate 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.

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?

No disease outbreaks likely to impact on English seal populations have been identified in 2011.

PDV is known to be a recurring disease and there is a possibility of another outbreak in the next few years. Preliminary results of blood tests from harbour and grey seals caught at the Farne Islands and in St Andrews Bay suggest that PDV is not currently circulating in the UK. However, epidemiological models of PDV in European waters suggested an inter-epidemic period of approximately 13 years. Given that the last outbreak was in 2002, and that this was 14 years after the first outbreak, another epidemic might be expected within the next few years. 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 small and localised outbreak of seal pox at the Farne Islands in 2011 appears to have ended.

[21] Aarts et al. (2008) Estimating space use and habitat preference from wildlife telemetry data. *Ecography* **31**:140-160

An outbreak of influenza among harbour seal pups on the east coast of the US in New England in 2011 caused an unusual mortality event to be declared. An H3N8 influenza A virus, closely related to avian influenza, killed at least 162 pups before fading out of the population by the end of the year. This disease has not yet been seen in the UK or Europe although there is serological evidence that influenza B may be circulating in the Wadden sea.

Seal populations

8. 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?

See answer to Scottish Government Question 1 above.

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

See answer to Scottish Government Question 1 above.

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

The population of harbour seals on the English east coast has not declined since the 2002 PDV epidemic and recent counts suggest that it is now increasing (see Question 17 below)

11. 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?

According to recent moult and pupping season surveys the harbour seal populations in England are not declining (see Question17 below). For information on Scottish populations see answer to Scottish Government Question 5 above.

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

Marine Scotland commissioned SMRU to host a workshop with national and international researchers and population managers to explore the current state of knowledge and identify future research and management strategies. The workshop was held immediately before the SCOS 2012 meeting. The report from the workshop should provide an answer to this question and was made available to stakeholders shortly after the workshop and to SCOS 2013.

Additional questions concerning the relationship between harbour seal populations in the southern North Sea and the apparent southward shift in foraging effort by grey seals in the summer months are likely to become more important in future (see Question 17 below). In combination with the rapidly increasing breeding population of grey seals this represents a major shift in seal populations and seal foraging effort. Assessing the likely effects on harbour seal populations will become a pressing issue in the near term.

Investigating the causes, geographical extent and intensity of the mortalities due to corkscrew injuries is likely to become a major requirement for both local and national seal population management. Seals are not included in the remit of the Defra-funded UK Cetacean *Strandings* Investigation *Programme.* At present although dead seal reports are collated by the UK CSIP there is no established programme to investigate cause of death.

The transient links between seal populations

13. Is there any evidence that seals move between protected sites and have any passages been identified?

Extensive studies of movements by both grey and harbour seals have been conducted over the past 20 years. Results indicate that a large proportion of the grey seals made extensive movements between protected areas. For example it is not uncommon for grey seals tagged in the Firth of Tay to move to the Northern Isles and/or the southern North Sea, a range that encompasses several protected areas. For harbour seals, both the frequency and extent of movements are more restricted. There are however records of movements of adult seals between Orkney and Shetland, Orkney and Moray Firth and between all the English east coast sites. Pup movements may be more extensive, within the small sample satellite tagged in Orkney, individuals moved to Shetland, the Outer Hebrides and the Moray and Tay Firths. An analysis of the relationship between foraging and breeding site use by grey seals has been published[22].

Extensive movements of grey seal pups between sites in North Wales and those in both Southern Ireland and the Isles of Scilly have been recorded in recent telemetry studies and an adult grey seal tagged and then observed foraging in Brittany then moved to the Inner Hebrides to forage.

Harbour seals are usually regarded as more restricted in their movements, but recent telemetry studies have shown movements between haulout sites in southern Netherlands and the English east coast, between Normandy and the English south coast and within the UK there appears to be extensive movements between the Wash and haulout sites the Thames and Kent. In addition, there are recorded movements of pups between all English east coast sites and some records of movements between the Netherlands and the English east coast.

The rest of the answer depends on the meaning of ‘passages’. If ‘passages’ is interpreted to mean movement from one site to another, then the answer is given above. If ‘passages’ is interpreted to mean corridors, the answer is more

[22] Russell, D. J. , McConnell, B. J. , Thompson, D. , Duck, C. D. , Morris, C. , Harwood, J. & Matthiopoulos, J. (2013) Uncovering the links between foraging and breeding regions in a highly mobile mammal : *Journal of Applied Ecology*. 50, 2, p. 499-509.

complicated. Grey seals' movement patterns are highly variable and the routes between distant foraging and/or haulout sites are not clearly defined nor apparently are they tightly constrained.

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

There is little information on risks in general and no information on risks specific to movements between protected areas.

Seal diet

15. *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?*

A Scotland-wide, seasonally structured study of harbour and grey seal diet is underway with funding from Scottish Government (see answer to Scottish Government Question 7 above). Additional funding from Natural England has allowed SMRU to expand this study to haulout sites on the east coast of England at sites in Northumberland, Lincolnshire and Norfolk. Estimates will be available for SCOS 2013 and a summary of progress to date is presented in SCOS-BP 12/08. In addition to the current substantial project where data collection has been designed to provide representative samples by region and season, a small subset of sites have been identified where a long-term program of regular grey and harbour seal scat collection would be useful. These are: Donna Nook (quarterly collections); Blakeney point (collections during breeding and moult); and Forvie NNR in the Ythan Estuary (monthly collections). However, at present there is no funding to continue these collections or process samples and analyse the results.

SMRU are also conducting a series of laboratory based feeding trials to determine digestion coefficients for harbour seals to allow direct comparisons with existing grey seal digestion coefficients (SCOS-BP 12/08).

In order to use basic seal diet data to predict consumption under different conditions we need to determine how prey selection and consumption will vary as relative and absolute prey abundances change. A study to derive a multi-species functional response for grey seals is underway involving SMRU and DTU Aqua.

The results of these studies, in conjunction with studies of seal distribution and abundance (SCOS-BP 12/01, 12/03 & 12/05), will allow us to describe diets and estimate fish consumption for both seal species by region and describe smaller scale temporal variations than has been possible to date.

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

There is no new information to alter the answer given in response to this question in SCOS Advice 2011.

Seal legislation

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

There is no new information to alter the answer given in response to this question in SCOS Advice 2011.

SCOS does not see a need to change the definition of the close season for grey seals. At present there is a conservation order in force along the entire east coast of England and Scotland. This order protects almost the entire English harbour seal population. While this is in force the close season is effectively extended to the whole year.

The Wash

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

Harbour seals

The 2011 count in the Wash was 2,894 which was approximately 6% lower than the 2010 peak count but almost identical to the mean 2009 count**.** Results of surveys conducted in the Wash in 2010 are reported in SCOS-BP 12/2 and described briefly in answer to Scottish Government Questions 1 & 3. One count was obtained in 2011 during the annual moult in August.

Overall, the combined count for the English East coast population (Donna Nook to Scroby Sands) in 2011 was 8% lower than the 2010 count. However, this was 26% higher than the mean of counts between 2004 and 2008. The 2011 total count was therefore close to the pre-epidemic count in 2002 (SCOS-BP 11/3, Figure 7, Table 4). The 2011 estimated peak pup count for the Wash was 23% lower than the 2010 estimate, and was therefore close to the 2009 count, which was 14% higher than the peak count in 2008. Despite these large increases, the English population has not kept pace with the rapid growth in the nearest European population in the Wadden Sea which increased by 9% between 2010 and 2011 and has grown by approximately 12% pa since the 2002 PDV epidemic.

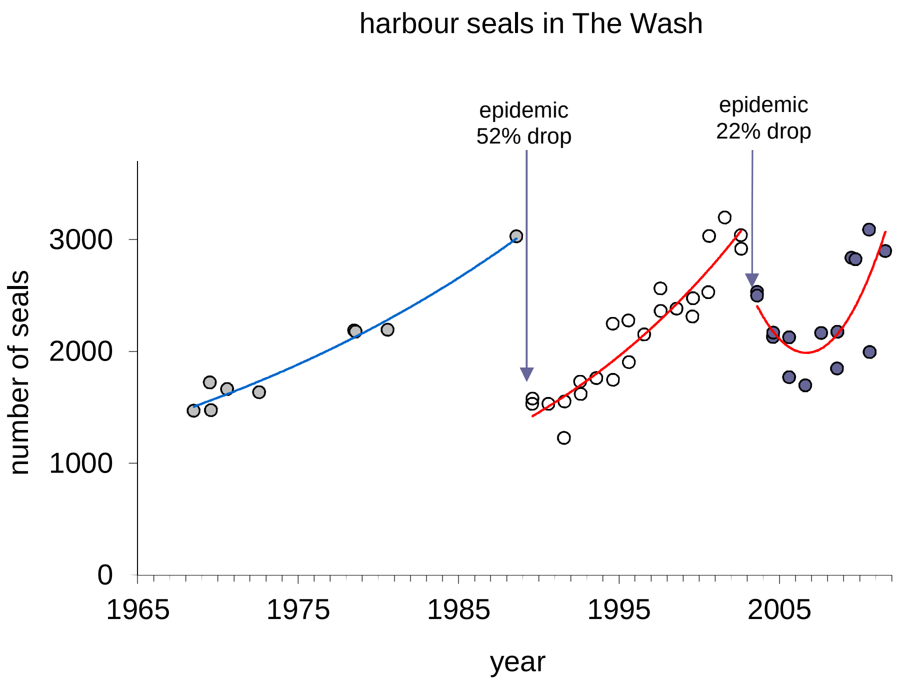


Fig. 7. Counts of harbour seals in The Wash in August, 1967 - 2011. These data are an index of the population size through time. Fitted lines are exponential growth curves (growth rates given in text) with a 2^{nd} order polynomial for post-2002 counts for illustration.

Grey seals

There are no breeding grey seals in the Wash, although there are large and rapidly increasing breeding colonies at Donna Nook in Lincolnshire and at Blakeney Point in Norfolk. Pup production trajectories for both were discussed in SCOS BP 11/1.

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 8). 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.

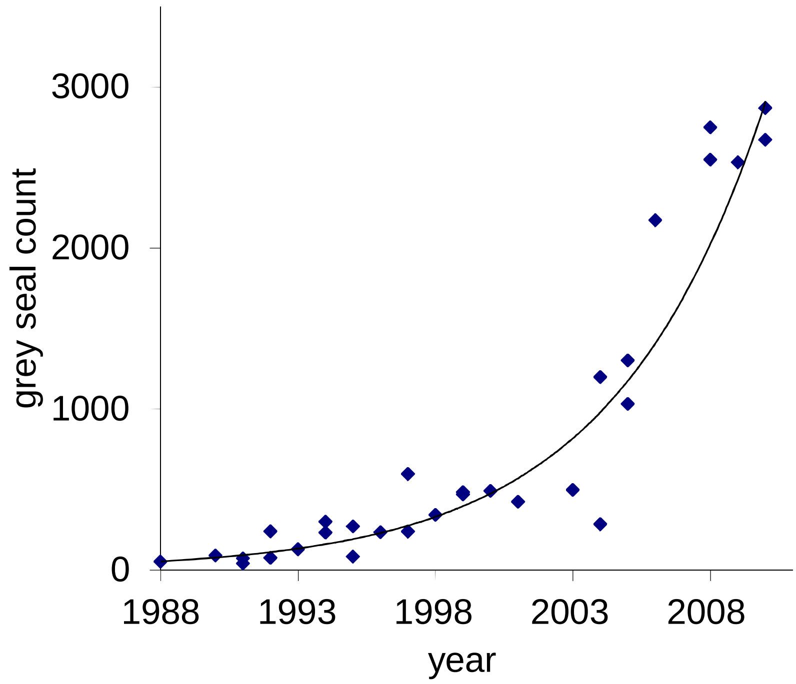


Fig. 8. Counts of grey seals hauled out in Lincolnshire, Norfolk and Suffolk during August over the period 1988 - 2010. Fitted line is an exponential curve with an annual rate of increase of 18% (R^2 = 0.87).

19. 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?

There has been a rapid increase in the numbers of seals counted in eastern England over the last two to three years. The most recent counts are similar to the pre-epidemic counts in 2001 and 2002. The recent rapid increase is too fast to be due to internal population growth and may indicate immigration. At present the reasons for the lag in recovery are unknown. However, the rapid increase in foraging effort by grey seals in the region may have been a factor.

Results of annual air surveys during the harbour seal moult (August) show that since 2000 the number of grey seals counted at haulout sites has increased dramatically, by an average of >25% p.a. This exceeds the growth in population associated with the rapidly expanding grey seal breeding populations in the southern North Sea. There must therefore be increased temporary immigration into the southern North Sea during the summer. This increase in grey seal foraging effort means that the total amount of seal foraging effort by both species in combination has increased rapidly in the south-western part of the North Sea.

This increase in grey seal foraging activity may be partly responsible for the lower growth rates of English harbour seal populations compared to neighbouring European populations in the Wadden Sea. Direct competition has not been documented, but SMRU are assessing the diet of the two species for overlap. Simultaneous telemetry tracking data are available in some locations and SMRU are examining those for evidence of foraging site overlap.

Seals and salmon netting stations

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

See answer to Scottish Government Question 8 above

Seals and fish farms

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

See answer to Scottish Government Question 9 above

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

22. What is the regularity of such an occurrence?

SCOS is not aware of any information on the frequency or timing of such occurrences in English rivers. The results of a study of this issue in Scottish rivers have recently been reported to Scottish Government and are described briefly in answer to Scottish Government Question 8 above.

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

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

24. What are effective deterrents in such freshwater locations?

Trials of the use of ADDs to deter seals in freshwater, particularly rivers are underway, funded by Marine Scotland Science. These are described briefly in answer to Scottish Government Question 8 & above.

25. What damage to salmon stocks is there as a result of seals in freshwater?

There is no new information to alter the answer given in response to this question in SCOS Advice 2011. SCOS is not aware of any information on the scale of damage to salmon stocks in English rivers. The results of studies in Scottish east coast rivers were described briefly in answer to Scottish Government Question 7 in SCOS 2011.

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

There is no new information to alter the answer given in response to this question in SCOS Advice 2011. SCOS is not aware of any information on numbers of complaints of seal damage in England.

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

There is no new information to alter the answer given in response to this question in SCOS Advice 2011. SCOS is not aware of any information on numbers of seals being killed in England to prevent damage to fisheries during the 'open seasons'. A seal licence is not 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.

28. 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?

There is no new information to alter the answer given in response to this question in SCOS Advice 2011. SCOS is not aware of any information on numbers of seals being killed in England under the 'fisherman's defence'. Again, as this does not require a licence under the Conservation of Seals Act there are no reporting requirements in England and therefore no reliable records.

The same information for Scotland and Wales would also be of interest if not available for England or for comparison with figures from England.

The killing of any seal in Scotland must now be carried out under licence under the new Marine (Scotland) Act and all such events, for whatever purpose must be reported. Summary information from licence returns is available on Marine Scotland's web site at *www.scotland.gov.uk/Topics/marine/Licensing/SealLicensing*

29. *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? (not asked in 2010)*

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 Scottish Government Questions 8 and trials of a novel device targeting seal startle responses is currently undergoing field trials at a fish farm in western Scotland.

The use of ADDs at fish farms 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.

A simple test of such effects could be achieved using fine scale GPS telemetry systems as part of directed behavioural response trials.

Shooting

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

A series of tests of the effectiveness of different firearms for killing seals is underway. Preliminary results should be available in time for discussion at the SCOS 2013 meeting.

31. *What is the likelihood of someone killing a seal with the first shot if they are not trained marksmen? – taking into account distance of the shot, an appropriate point of impact and stability of firing position.*

There is no new information with which to modify the answer given to this question in the SCOS 2011 Advice.

32. *Is there any evidence of the noise from such firearms effectively deterring seals from a net?*

There is no new information with which to modify the answer given to this question in the SCOS 2011 Advice. There is anecdotal evidence that individual seals will habituate to the sound of gun fire. Evidence from seal haulout sites in Air Force bombing and gunnery ranges suggests that they can habituate to extreme fire arms noise.

33. What is the likelihood of a marksman being able to correctly identify between seal species in the water? (We already have an idea as to the answer to this questions – in that it is difficult, but supporting evidence on this if it is possible would be helpful to us). (not asked in 2010)

This is impossible to answer. It is illegal to shoot a seal without properly identifying it in Scotland and during the close seasons for both species in England. No marksman should ever take a shot at ranges where it is not possible to clearly make out the features of the target. The Scottish code of practice sets a range of 150 metres as the maximum allowable range for shooting at seals. It should be a requirement that marksmen clearly and unequivocally identify the species of seal before taking a shot.

Although superficially similar it is relatively easy to tell adult grey and harbour seals apart. Marine Scotland have established a program of training for marksmen as part of the new licencing system in Scotland. Information on seal identification is available on Marine Scotland's web site at :

http://www.scotland.gov.uk/Resource/Doc/295194/0104521.pdf

Marine renewables

34. What research is currently underway in relation to possible impacts of marine renewable energy development (offshore wind, wave or tidal) on seals?

See answer to Scottish Government Question 10 above.

35. What value might there be in developing guidance on possible mitigation measures to avoid disturbance to seals (and other marine mammals) during marine renewable construction or installation along the lines of the JNCC "Guidelines for Minimising Acoustic Disturbance to Marine Mammals from Seismic Surveys"? (see link - http://www.jncc.gov.uk/pdf/Seismic_survey_guidelines_200404.pdf)

Pile driving is the loudest man made sound source in UK waters. Its use will expand and intensify as offshore wind farm developments accelerate. Standardised guidelines for mitigation of pile driving noise have been developed by the Statutory Nature Conservation Agencies[23].

[23] Statutory nature conservation agency protocol for minimising the risk of injury to marine mammals from piling noise. JNCC.available at http://www.jncc.gov.uk/page4274

All marine renewable energy projects have to meet assessment requirements of the national/local permitting processes. These usually require an extensive environmental impact assessment that should include a comprehensive risk assessment and proposed mitigation measures. Information on the effectiveness of a range of such measures would be useful to both the industry and the regulators. Unlike the marine seismic industry, most tidal devices will have significant individual requirements due to local conditions and device characteristics. It will therefore be a more difficult task than that faced by the authors of the seismic survey guidelines.

Climate change

36. 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?

At present there is no direct evidence of significant effects of climate change on seal populations. However, indirect effects, including exposure to novel biotoxins, disease agents and parasites and possible changes in prey availability, which are difficult to detect and document, are potential factors in the recent declines in common seals in Shetland, Orkney and along the northern North Sea coasts.

The precautionary position would be to assume that climate change is more likely to add stresses to populations than to be either neutral or beneficial. In these circumstances, practical measures to actively manage human factors that may either intentionally or inadvertently add additional stress to seal populations need to be encouraged.

In practice, we need to maintain or improve our power to detect effects through maintenance and improvement of data collection and ensuring that, whenever practical, we have the capacity to quickly introduce new management approaches. Some of changes suggested to the Conservation of Seals Act will help to enhance data flow and the power to detect changes. Depending upon how they are implemented, they could also result in a more rapid response to the evidence of effects.

SCOS recommends that a study of the effects of environmental factors on aspects of the foraging behaviour and diet and their consequences for reproductive success and survival of grey and harbour seals should be made a priority.

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.J.Hall,	SMRU, University of St Andrews;
Dr S. Wanless	N.E.R.C. C.E.H, Edinburgh;
Dr J. Greenwood,	CREEM, University of St Andrews;
Dr Stuart Middlemas	Marine Scotland-Science, Pitlochry;
Dr A. Bjørge,	Institute of Marine Research, Bergen, Norway;
Dr G. Englehardt,	CEFAS, Lowestoft;
Professor G. Ruxton,	University of Glasgow;
Dr Stuart B Piertney,	University of Aberdeen;
Dr James Cass (Secretary), NERC	NERC, Swindon

ANNEX II

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, 2012

12/01 Estimating the size of the UK grey seal population between 1984 and 2010, and related research.
L. Thomas

12/02 Priors for the grey seal population model:
M. Lonergan

12/03 The Status of British Harbour Seal Populations in 2011
C.D. Duck, C.D. Morris & D. Thompson

12/04 Harbour seal (Phoca vitulina) abundance within the Firth of Tay and Eden Estuary Special Area of Conservation: recent trends and extrapolation to extinction
M. Lonergan & D. Thompson

12/05 Marine distribution of grey & harbour seals around the UK
Jones, E. L., McConnell, B.J, Duck, C.D., Morris, C.D., Hammond, P.S., Russell, D.J.F. & Matthiopoulos, J.

12/06 Pup to adult photo-ID: evidence of pelage stability in grey seals
W. Paterson, P. Redman, L. Hiby, S. Moss, A. Hall & P. Pomeroy.

12/07 Method used to identify key seal haul-out sites in Scotland for designation under the Marine (Scotland) Act Section 117
C Morris, C Duck, M Lonergan, J Baxter, S Middlemas, & I Walker

12/08 The diet of harbour and grey seals around Scotland: update on progress
Wilson, L. and Hammond, P. .

12/09 Movements of recently weaned grey seal pups in Orkney: preliminary results from telemetry studies
D. Thompson

12/10 Movements and dive behaviour of harbour seals in high tidal energy areas in Kylerhea: preliminary results from telemetry studies
D. Thompson

Len Thomas

Estimating the size of the UK grey seal population between 1984 and 2011, using revised priors on demographic parameters.

NERC Sea Mammal Research Unit and Centre for Research into Ecological and Environmental Modelling, University of St Andrews, St Andrews KY16 8LB

Summary

We fitted two Bayesian state-space models 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 (2) an independent estimate assumed to be of total population size just before the 2008 breeding season. The two models allowed for density dependence in either pup survival (EDDSNM) or adult female fecundity (EDDFNM); both used a flexible form for the density dependence function, and assumed no movement of recruiting females between regions. Although the population models are identical to those used in previous briefing papers, the prior distributions on demographic parameters have been revised in light of new research findings as well as re-examination of previous research. The EDDSNM model was strongly favoured over the EDDFNM model, particularly in the light of the independent estimate of adult population size. Under the EDDSNM model, the estimated adult population size in 2011 was 122,300 (95% CI 80,300-178,200) using just the pup production estimates, and 93,000 (95% CI 76,100-116,300) using both pup production and independent population estimates.

Introduction

This paper presents estimates of population size and related demographic parameters, based on the models and fitting methods of Thomas (2010). Models are specified using a Bayesian state space framework, and fitted using a Monte Carlo particle filter. Two models of the population dynamics are used: one assumes density dependent pup survival and the other density dependent fecundity. Both allow extended forms of Beverton-Holt-like density dependence and assume no movement of females between regions; hence they are abbreviated EDDSNM and EDDFNM respectively. Informative priors are used on many model parameters; these priors have been revised compared with previous years, as detailed by Longeran (2012). Generally speaking, the new priors support a broader range of values for survival and fecundity. We compare the fit of the two models by calculating posterior model probabilities. We also compare results based on the new priors with those using the old ones.

Materials and Methods

The models used and fitting methods are identical to those used in previous years, and so are not repeated here. In summary, the models used are Bayesian state-space models, with the process model component (i.e., the population dynamics model) tracking the population numbers in 7 age categories (pups, age 1-5 females and age 6+ females), and the observation model linking data on estimated pup production to the pup numbers in the process model.

Priors on model parameters are given in Table 1, as well as the priors used in previous briefing papers, for comparison.

Neither the EDDSNM nor EDDFNM models 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 will investigate the use of this in a future revision of this briefing paper.

Table 1. Prior parameter distributions

	New priors			Old priors		
Param	Distribution	Mean	Stdev	Distribution	Mean	Stdev
ϕ_a	0.8+0.2*Be(1.6,1.2)	0.95	0.04	Be(22.05,1.15)	0.95	0.04
$\phi_{j\max}, \phi_j$	Be(2.87,1.78)	0.7	0.1	Be(14.53,6.23)	0.7	0.1
χ_1	Ga(4,2500)	10000	5000	Ga(4,2500)	10000	5000
χ_2	Ga(4,1250)	5000	2500	Ga(4,1250)	5000	2500
χ_3	Ga(4,3750)	15000	7500	Ga(4,3750)	15000	7500
χ_4	Ga(4,10000)	40000	20000	Ga(4,10000)	40000	20000
ρ	Ga(4,2.5)	10	5	Ga(4,2.5)	10	5
$\alpha, \alpha_{\max}$	0.6+0.4*Be(2,1.5)	0.95	0.04	Be(22.05,1.15)	0.95	0.04
ψ	Ga(2.1, 66.67)	140	96.6	Ga(2.1, 66.67)	140	96.6

Model fitting used a particle filtering algorithm identical to that of Thomas (2010). In essence this involves simulating seal populations according to the prior distribution of model parameters and weighting the simulations according to the data likelihood. Each simulation is called a "particle" and they are "filtered" according to the likelihood. Further details are given in Thomas and Harwood (2008). In this briefing paper, results were generated from 1,000 runs of 1,000,000 samples for the fixed CV model and 500 runs of 1,000,000 samples for the estimated CV model.

Model selection is not straightforward in state-space models when observation error is estimated. Hence, we did an initial set of 135 runs of 1,000,000 samples using the EDDSNM process model, and with the observation error parameter, ψ, sampled from its priors. We then took the posterior mean estimate from of ψ and used for subsequent runs of both the EDDSNM and EDDFNM models. Inferences are based on 1,500 runs of 1,000,000 samples for the EDDSNM model, and 550 runs of the same size for the EDDFNM model.

Results

Monte Carlo accuracy

The effective sample size (ESS) of unique particles is a useful measure of the accuracy of the simulation. For the fixed CV model, the ESS based on pup count data alone was 62.5 (Table 2), although this was reduced substantially (to 24.3) with inclusion of the independent population estimate. This reduction is not surprising given that the estimate was some distance from that implied by the pup count data and priors alone (see later in *Results*). ESSs in this region have been shown in previous briefing papers to produce population and parameter estimates accurate to around 2-3 significant figures; here we only require the observation error parameter from this model.. The ESS for the models where CV is estimated were rather higher for the EDDSNM model – not surprising given that more runs were devoted to this model – but disappointingly low for the EDDFNM model after inclusion of the independent population estimate. A large reduction in ESS for this model with introduction of the independent estimate is expected, as the population size estimates from pup count data alone are far from the total population size estimated in the independent survey.

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}).The first model assumed the CV on pup production was estimated; the other models assumed it was fixed (at the posterior mean estimate from the first analysis).*

Model	*K* ($\times10^7$)	*K** ($\times10^7$)	*U* ($\times10^4$)	ESS_{u1}	ESS_{u2}
EDDSNM CV Est.	350	9.7	10.9	62.5	24.3
EDDSNM CV Fixed	1500	14.1	16.4	378.3	72.4
EDDFNM CV Fixed	550	11.7	3.7	67.8	2.9

Observation error CV

Using the EDDSNM model where observation error CV was not fixed, posterior mean CV was 8.9% using pup production data alone, and was almost identical when the independent data was also used. This was only slightly different from the value found by Thomas (2011) (9.8%) using the old priors. Both numbers are similar to the prior mean of 8.4%. The fixed value of 8.9% was used in subsequent models reported here.

Comparison of models for density dependence with and without the total population estimate

Smoothed posterior means and 95% credible intervals for the two models are shown in Figure 1, both with and without the additional total population estimate. Both models showed similar fits to the pup production data alone; the addition of the total population estimate affected the fit of the EDDFNM model somewhat. There is evidence that the EDDSNM model tracks the observations slightly better than the EDDFNM, particularly after the addition of the total population estimate, but there is some evidence of Monte-Carlo error in the EDDSNM estimate for pup production error alone, with a slight discontinuity in the estimate around 2005-2007.
The models broadly provide a reasonable fit to these data, but there are some deficiencies, particularly with the EDDFNM model, which does not adequately capture the rapid rise and sudden levelling off in pup production in the Hebrides during the early 1990s, nor the recent levelling off in Orkney; the EDDSNM model both over-fits pup production in the North Sea in the late 1990s and early 2000s, but EDDFNM under-fits the recent increase. Overall, particularly the EDDSNM data fit is better than has been seen previously.

Posterior parameter estimates are shown in Figure 2. Parameter estimates are, for the survival and fecundity parameters, quite different from those reported in previous briefing papers (Thomas 2010, 2011) due to the new priors.

For the EDDSNM model, the posterior mode for adult survival is at the upper end of the prior, with a posterior mean of 0.96 with pup production data alone and 0.99 with the addition of the independent data. Conversely, maximum pup survival is estimated to be very low, with a posterior mean of 0.51 based on independent data alone, and 0.29 with the addition of the independent estimate. The fecundity parameter estimate is close to the prior, but shifted upwards slightly with the addition of the independent data. The density dependence parameter ρ is estimated reasonably precisely, with values of 5.4 and 7.3 based on pup production data alone and with addition of the independent data. These values are rather higher than estimates in previous years, and probably help account for the better fit, since pup production is able to level off quicker when close to carrying capacity.

For the EDDFNM model, the parameter estimates on adult survival seem more reasonable; priors on pup survival and maximum fecundity are close to their priors and the ρ is estimated to be smaller. Parameter estimates after addition of the 2008 independent data show clear evidence of Monte Carlo error.

Posterior model probabilities for the two models are shown in Table 3. There appears to be very strong evidence for the EDDSNM model over the EDDFNM, including or excluding the 2008 independent population size estimate. [Note however that I suspect an error in the calculation of the –LnIL based on pup production data alone, so this is subject to revision.]

Table 3. Number of parameters, negative log integrated likelihood (-LnIL) and posterior model probabilities (p(M)) for fit to pup production data from 1984-2010 and the additional total population estimate from 2008.

Model	# params	-LnIL	p(M)
Pup production data alone			
EDDSNM	8	1321.41	1.00
EDDFNM	8	1332.08	0.00
Pup production and total population estimate			
EDDSNM	8	1320.53	1.00
EDDFNM	8	1343.12	0.00

Estimates of total population size

Estimates of total population size from the EDDFNM model were more than twice those from the EDDSNM model, based on pup production data alone (Table 4 and Figure 3). Inclusion of the independent estimate of total population size from 2008 brought the estimates down by approximately 30% for the EDDSNM model and 50% for the EDDFNM model; it also narrowed the posterior credibility intervals, particularly of the EDDFNM model (Figure 3).

Table 4. Estimated size, in thousands, of the British grey seal population at the start of the 2011 breeding season, derived from models fit to pup production data from 1984-2010 and the additional total population estimate from 2008. Numbers are posterior means with 95% credibility intervals in brackets.

Pup production data alone		
	EDDSNM	EDDFNM
North Sea	25.6 (15.3 38.9)	37.1 (27.4 46.9)
Inner Hebrides	8.8 (6.2 12.3)	24.2 (18.9 31.2)
Outer Hebrides	32.5 (22.5 44.6)	96.4 (75.1 128.6)
Orkney	55.4 (36.3 82.5)	122.2 (93.9 155.1)
Total	122.3 (80.3 178.2)	279.9 (215.2 361.9)
Pup production and total population estimate		
	EDDSNM	EDDFNM
North Sea	19.2 (14 27.2)	22.8 (20.3 25.4)
Inner Hebrides	6.8 (5.8 8.3)	17.4 (15.8 18.7)
Outer Hebrides	25.2 (21.2 30.2)	66.8 (63.7 74.6)
Orkney	41.7 (35.1 50.6)	80.2 (73.6 84.7)
Total	93 (76.1 116.3)	187.3 (173.4 203.4)

Discussion

The new priors produce estimates that are slightly lower than those from the old priors, once the independent estimate has been included in estimation. For example, Thomas (2011) gave the total population size in 2010 using the EDDSNM model as 99,300 (95%CI 80,200-122,900), while the estimates from this analysis for that year are 92,500 (95%CI 76,200-114,500). One explanation for this is that the wider priors on parameters produce wider posteriors on population size from pup production data alone, hence causing the independent 2008 estimate of population size to be weighted more heavily in the calculations.

The change in posterior parameter estimates caused by the new priors deserves further examination – particularly the high adult survival estimates and very low pup survival estimates from the EDDSNM model.

The analysis presented here should be extended to allow for uncertainty in sex ratio of adults. Priors on the sex ratio parameter are given by Longeran (2012), and an analysis based on this will be presented at the SCOS meeting.

References

Longeran, M. 2012. Priors for grey seal population model. *SCOS BP 12/02*.

Thomas, L. 2010. Estimating the size of the UK grey seal population between 1984 and 2009. *SCOS Briefing Paper 10/2*. [Updated 16th March 2011.]

Thomas, L. 2011. Estimating the size of the UK grey seal population between 1984 and 2010. *SCOS Briefing Paper 11/2.*

Thomas, L. and J. Harwood. 2009. Estimating the size of the UK grey seal population between 1984 and 2008. *SCOS Briefing Paper 09/2*

Figure 1. Posterior mean estimates of true pup production for 1984-2011 from two models of grey seal population dynamics, fit to pup production estimates from 1984-2010 (circles) and a total population estimate from 2008, assuming the CV of the pup production estimates is 8.9%. Lines show the posterior mean bracketed by the 95% credibility intervals for the EDDSNM (blue) and EDDFNM models (red).

(a) Pup production data only

(b) Pup production data and 2008 total population estimate

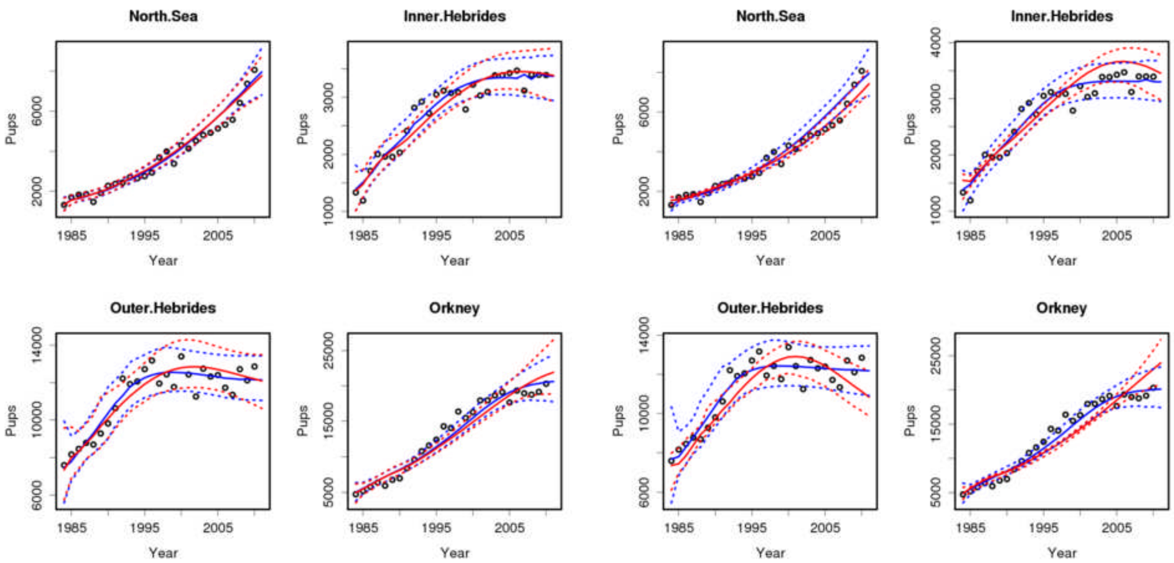
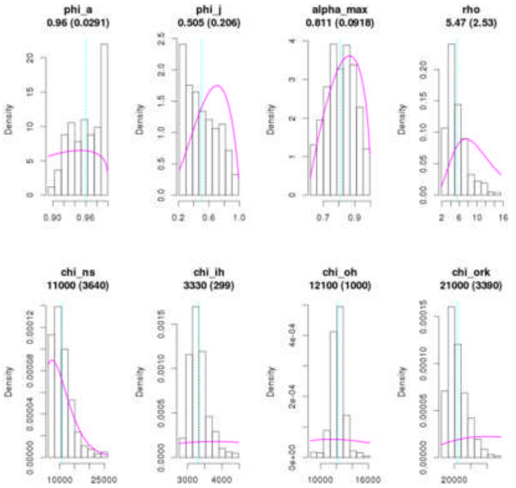


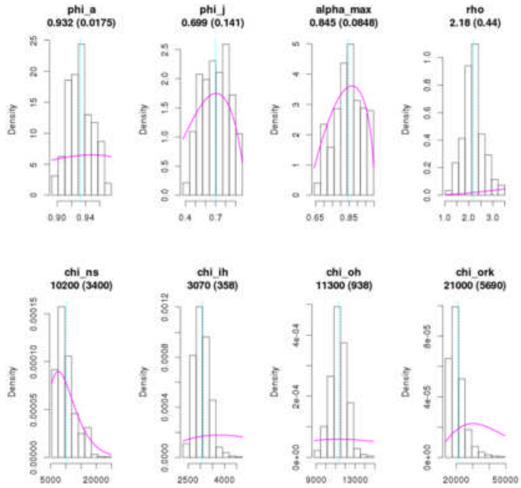
Figure 2. Posterior parameter estimates (histograms) and priors (solid lines) from two models of grey seal population dynamics, fit to pup production estimates from 1984-2010 (circles) and a total population estimate from 2008. The vertical line shows the posterior mean, its value is given in the title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

Pup production data only

(a) Extended density dependent survival no movement (EDDSNM)

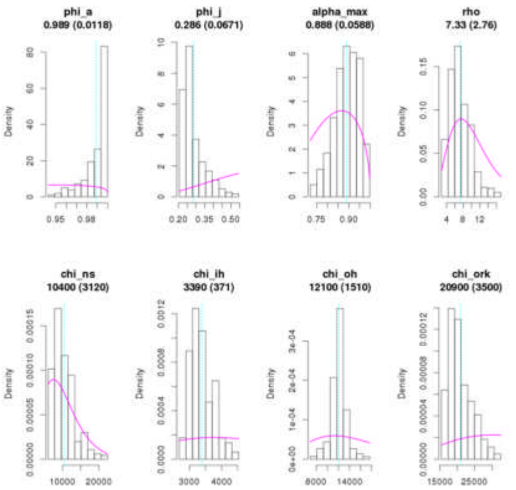


(b) Extended density dependent fecundity no movement (EDDFNM)



Pup production data and 2008 population estimate

(c) Extended density dependent survival no movement (EDDSNM)



(d) Extended density dependent fecundity no movement (EDDFNM)

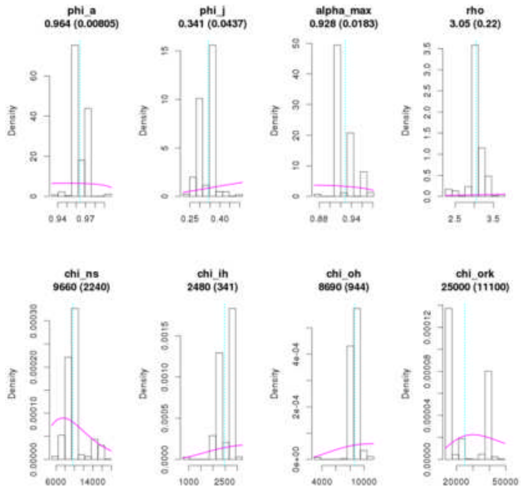
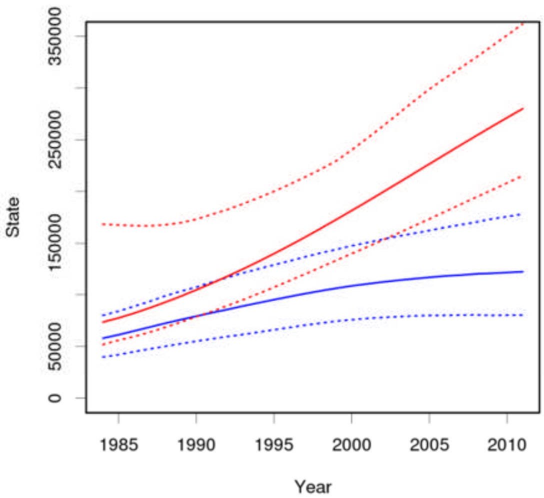
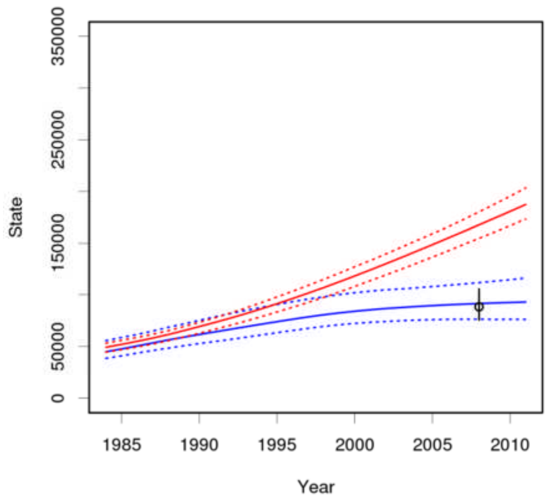


Figure 3. Posterior mean estimates of total population size in 1984-2011 from two models of grey seal population dynamics, fit to pup production estimates from 1984-2010 and a total population estimate from 2008 (circle, with horizontal lines indicating 95% confidence interval on the estimate), assuming the CV of the pup production estimates is 8.9%. Lines show the posterior mean bracketed by the 95% credibility intervals for the EDDSNM (blue) and EDDFNM models (red).

(a) Pup production data only



(b) Pup production data and 2008 total population estimate



Appendix

Estimates of total population size, in thousands, at the beginning of each breeding season from 1984-2011, made using the EDDSNM (extended density dependent survival with no movement) model of British grey seal population dynamics fit to pup production estimates and a total population estimate from 2008. Numbers are posterior means followed by 95% credibility intervals in brackets.

Year	North Sea	Inner Hebrides	Outer Hebrides	Orkney	Total
1984	4.1 (3.5 5)	4.4 (3.6 5.4)	20.4 (17.4 25.4)	15.9 (13.8 19.7)	44.7 (38.4 55.5)
1985	4.4 (3.8 5.3)	4.6 (3.9 5.7)	21.5 (18.3 26.8)	16.9 (14.8 20.7)	47.4 (40.7 58.5)
1986	4.7 (4.1 5.7)	4.9 (4.2 6)	22.7 (19.4 27.8)	18.1 (15.8 22)	50.4 (43.4 61.5)
1987	5 (4.4 6.1)	5.2 (4.4 6.3)	23.6 (20.2 28.7)	19.3 (16.9 23.6)	53.2 (45.9 64.8)
1988	5.4 (4.7 6.6)	5.6 (4.7 6.7)	24.5 (21 30)	20.7 (17.9 25.1)	56.2 (48.2 68.4)
1989	5.8 (5 7)	5.8 (4.9 7.1)	25 (21.4 30.8)	22.2 (19.2 26.8)	58.8 (50.5 71.7)
1990	6.2 (5.3 7.6)	6.1 (5.2 7.4)	25.3 (21.7 31.6)	23.8 (20.5 28.6)	61.4 (52.7 75.2)
1991	6.6 (5.7 8.1)	6.4 (5.4 7.7)	25.6 (21.9 32.1)	25.4 (21.7 30.7)	64 (54.7 78.6)
1992	7.2 (6 8.7)	6.6 (5.5 8)	25.6 (22 32.4)	27.1 (23.2 32.8)	66.5 (56.7 81.8)
1993	7.6 (6.4 9.3)	6.7 (5.6 8.2)	25.8 (22.1 32.5)	28.8 (24.7 34.9)	69 (58.8 84.9)
1994	8.2 (6.9 9.9)	6.8 (5.7 8.4)	25.8 (22.2 32.4)	30.6 (26.3 37)	71.5 (61 87.8)
1995	8.7 (7.3 10.6)	6.9 (5.7 8.6)	25.8 (22.2 32.3)	32.4 (28 39.1)	73.9 (63.2 90.6)
1996	9.3 (7.8 11.3)	7 (5.8 8.6)	25.8 (22.2 32.1)	34.2 (29.6 41.2)	76.2 (65.3 93.3)
1997	10 (8.4 12.1)	7 (5.8 8.7)	25.7 (22.2 31.9)	35.8 (31.1 43)	78.5 (67.4 95.8)
1998	10.6 (8.9 13)	7 (5.8 8.7)	25.7 (22.2 31.7)	37.2 (32.4 44.7)	80.6 (69.3 98)
1999	11.3 (9.5 13.8)	6.9 (5.9 8.6)	25.6 (22.1 31.4)	38.6 (33.5 46.4)	82.4 (70.9 100.2)
2000	12 (10.1 14.7)	6.9 (5.9 8.6)	25.6 (22 31.1)	39.5 (34.3 47.6)	84 (72.2 101.9)
2001	12.8 (10.7 15.6)	6.9 (5.9 8.5)	25.5 (21.8 30.9)	40.3 (34.8 48.6)	85.4 (73.3 103.5)
2002	13.5 (11.4 16.5)	6.9 (5.9 8.5)	25.4 (21.7 30.7)	40.8 (35.1 49.2)	86.6 (74.1 104.9)
2003	14.3 (12 17.4)	6.9 (5.9 8.3)	25.4 (21.7 30.5)	41.1 (35.2 49.4)	87.7 (74.8 105.7)
2004	15 (12.6 18.2)	6.9 (5.9 8.3)	25.3 (21.7 30.4)	41.4 (35.3 49.8)	88.6 (75.4 106.7)
2005	15.8 (13 19.2)	6.8 (5.9 8.3)	25.3 (21.7 30.3)	41.6 (35.3 50.1)	89.5 (75.9 108)
2006	16.5 (13.3 20.4)	6.9 (5.9 8.3)	25.3 (21.7 30.3)	41.6 (35.3 50.3)	90.2 (76.1 109.2)
2007	17.1 (13.5 21.6)	6.8 (5.9 8.3)	25.2 (21.6 30.2)	41.7 (35.3 50.3)	90.9 (76.3 110.4)
2008	17.7 (13.7 22.8)	6.8 (5.9 8.3)	25.2 (21.6 30.2)	41.7 (35.2 50.4)	91.5 (76.3 111.7)
2009	18.2 (13.7 24.1)	6.9 (5.9 8.3)	25.3 (21.5 30.3)	41.6 (35 50.5)	92.1 (76.1 113.2)
2010	18.8 (13.9 25.6)	6.8 (5.8 8.3)	25.2 (21.4 30.1)	41.7 (35.1 50.5)	92.5 (76.2 114.5)
2011	19.2 (14 27.2)	6.8 (5.8 8.3)	25.2 (21.2 30.2)	41.7 (35.1 50.6)	93 (76.1 116.3)

M. Lonergan

Priors for the grey seal population model:

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Overview

The grey seal population model uses a set of demographic parameters to estimate total abundance from counts of pups observed during aerial surveys of breeding colonies. This rescaling is done in three stages. The first stage, which is not discussed here, estimates annual pup production from the observations. The second involves fitting a detailed Bayesian model to estimate the total number of females in the population. In the third stage, this is multiplied by an estimate of the ratio of males to females in the population to give the final estimate The independent population estimate shows that density dependence lowers the survival of female pups, rather than fecundity.

The population model requires a prior distribution for each demographic parameter. Another distribution is required to represent the uncertainty in the assumed sex-ratio of the population. This document presents revised priors that may be more appropriate than the ones presently being used. They were discussed, and some were agreed to be appropriate, at a meeting of SMRU staff on 10/4/12 (participant list on p41).

This document represents a current best estimate of the priors, largely based on published work. More detailed re-examination of these datasets might allow these priors to be refined further. Issues that remain to be addressed are listed at the end. Table 1 compares the suggested and previously used distributions.

Table 1: Priors for the grey seal model

Parameter	Priors		Agreed at 10/4/12 meeting?	Pages containing reasoning
	Old	New		
Pup surv.l	Beta(14.53,6.23)	Beta(2.87,1.78)	No	2-5
Juvenile survival	Same as adult survival	Same as adult survival	No	6
Age at first breeding*	6	6	No	7-8
Fecundity	Beta(22.05,1.15)	0.6+0.4*Beta(2, 1.5)	Yes**	9-12
Adult surv.	Beta(22.05,1.15)	0.8+0.2*Beta(1.6,1.2)	Yes	13-29
Sex ratio	1.73	1+Gamma(0.1,2)	No	30-38

*Age of first breeding is actually a choice about model structure, rather than a prior, but is included here for completeness.

** The prior given here does not match the one that was agreed at the meeting, having been modified in later discussions.

Female pup survival at low population densities.

Summary

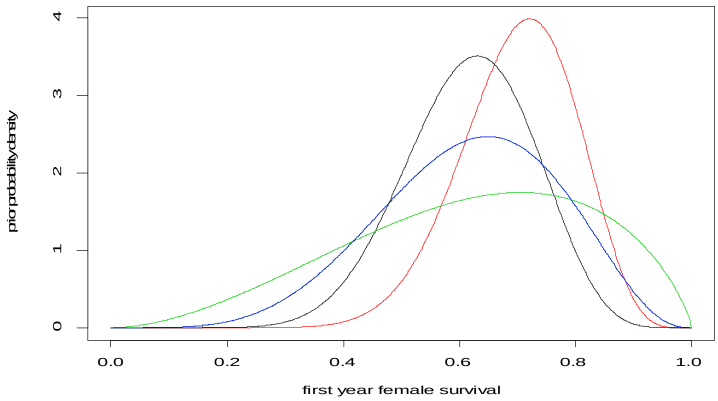
The current prior on female pup survival at low population densities is beta(14.53,6.23), which gives a mean of 0.7 and a standard deviation of 0.1. A more appropriate prior might be centred on 0.6, and have a lower precision than that currently used.

Tasks identified in 10/04/12 meeting:

- A reanalysis of the three Hall datasets, as well as the older flat tag data, would be required to fully utilise them. The newer telemetry data would also need to be analysed to extract relevant information from it.

- Need to look at juvenile 2-5 yr old survival (Bowen et al 2007 paper).

Provenance of current estimate
Harwood and Prime (1978) tabulate the pup survival rates that would give a 7%pa population growth rate for various plausible values of adult survival and fecundity. They suggested 0.66 for pup survival assuming annual survival of 0.93 from age 1 and fecundity of 0.9 from age 6.



Relevant data

Hall *et al.* (2001) paper.
This estimates first year female survival at 0.617 (SE=0.155), which can be approximated with a beta(11.45,7.11). This looks a bit different from the currently used prior (Figure 1).

Hall *et al*. fitted a detailed model to their data. It appears to describe and represent the data well. However there are some details of the data that might complicate its use as representative of this parameter in the wider population:

1) as Hall *et al*. point out, their data comes from one island and year and their evidence of an effect of condition (mass/length) at weaning on survival could indicate that the overall survival probabilities are more variable than the estimates in the paper.

2) Less than half of the tags were observed after the animals had left the breeding colony. The results depend on the proportion of those animals that are believed to have died (rather than just been missed).

3) Changes in effort over time were included as either a factor with separate values for each two month period or a seasonal (winter summer) factor. A steady increase in recapture efficiency, arising from increasing knowledge of the animals and their behaviour, might bias estimates of survival or emigration. Opportunistic resightings account for 60% of all observations of tagged animals. Increasing public awareness, especially if it occurred differently in different areas, could therefore have a similar effect on the results.

4) Survival rates were considered to either be constant throughout the study or to vary between all six study periods. The difference between these models was 10 parameters and a ΔAICc of around 10. If there was actually a gradual change in survival rates, or a pulse of high mortality, an intermediate model might beat both of these. Simple binomial gams fitted separately to the recaptures and resights for each sex suggest a non-exponential pattern through time for females (but not males). While there would be a risk of producing artefacts by fishing through a larger set of models, it is not obvious how non-exponential patterns might affect the results.

5) The high levels of emigration (35% per 2 month period; over 90% over the year) resulted in half the opportunities to resight individuals occurring away from the main colonies studied. Those observations also provide the only information to separate emigration from mortality for this age-group. If the resighting effort is concentrated in certain areas, and therefore misses individuals that emigrate to other areas, emigration will be underestimated and mortality over-estimated (though that would seem hard to reconcile with the high estimate of emigration). Any colony where most pups emigrate would require a high level of immigration to sustain its growth. The current age-structured models animals treats all redistribution of females as occurring at age six, and there is no relevant information available on juvenile movements.

6) The recovery rates for tagged carcasses detached tags were surprisingly high (12 of each from around 120 deaths).

Hall *et al.* (2002)
This reanalysed half the data from Hall *et al.* (2001) along with data from another 158 similar tags attached in the Farne Islands. The best model they identified had different survival probabilities in each two-month period. The uncertainty around the last two-month estimates was very large (more than would occur with all the probability mass concentrated at probabilities of 0 and 1). Table 2 gives estimates for annual survival generated by multiplying the two-monthly survival rates, and also 10-month survival estimates that miss out the problematic final period. The confidence intervals are very conservative because they ignore the interdependence between the two-monthly estimates.

Table 2: Survival rates for female grey seals estimated from data in Hall *et al*. (2002). The confidence intervals for the first column of estimates are generated by multiplying draws from beta distributions with the same means and standard deviations as given in Table 6 of Hall *et al*. (2002). For the final two-month periods, where it was impossible to do that directly, a beta distribution was used with the appropriate mean and the first shape parameter fixed at 0.001. The ten-month estimates leave out the final two-month period.

Location	Annual survival	10-month survival
Isle of May	0.41 (0, 0.74)	0.54 (0.29-0.76)
Farne Islands	0.03 (0, 0.14)	0.07 (0.01, 0.16)

The ten-month survival estimates for the two areas are significantly different (p<0.01), even with the very conservative confidence intervals. This large difference in survival rates is not obvious from the summerised data presented by Hall *et al.* (in their Table 2). It may be that the model fitting had difficulty with the combination of the low opportunistic resighting rates (estimated at 0.02 in the Isle of May in winter) and the limited area those authors were able to systematically survey to make visual recaptures. These issues may also limit the information that could be obtained from detailed re-examination of these data.

Hall *et al.* (2009)
In 2002 mobile phone tags were attached to 27 grey seal pups as part of a study on the Isle of May. *Tags lasted 6 months due to battery life, so survival estimates were calculated for the period December to June and annual estimates were adjusted accordingly.*

- data was received from 55 of the 60 tags in the study.
- scaling up to a full year gave an *estimated annual survival probability for* […] *females of 63.9% (after accounting for the effect of tag loss.*)
- it is not obvious from the paper that a constant recapture rate improves thefit of the model to the data. They state*: Lower recaptures in February to April probably reflect an exploratory behavioural phase where the pups disperse to sea before establishing regular foraging patterns*

Pomeroy *et al.* (2010)
That study looked at the recruitment into the breeding population at North Rona of 996 female grey seal pups tagged between 1979 and 2000 and 1260 tagged on the Isle of May between 1990 and 2005. The authors observed 1.7% of the North Rona animals returning as adults and 7.5% of the Isle of May ones. There was substantial interannual variation and a gradual decline in the proportions of animals being observed to have returned. Tag loss in adults was estimated by various methods to be between 2% and 10%. Even at 20%, it should leave 1/3 of tags visible after 5 years.

For the 1998 Isle of May cohort, which was also used in the Hall *et al.* study, 1 out of 51 tagged individuals were re-sighted as adults. The high level of emigration detected by Hall *et al.* may explain the apparent discrepancy: each female could recruit to one of the colonies she is familiar with, rather than returning to the one she was born at. If that interpretation is true, it would require studies of recruitment rates to cover multiple colonies. Alternatively, the survival rates of 2-5 year old females may be lower than those for adults.

Conclusion:
There don’t seem to be any obvious systematic biases in Hall *et al.*’s estimates of annual survival. It would be possible to fit some additional models with pup survival gradually varying, but there seems no obvious reason to expect that to produce very different results. The major difficulty with their 2001 & 2002 studies comes from their dependence on small numbers of observations reported by members of the public, though it would seem difficult to reconcile a substantial effect from incomplete coverage of the areas into which pups emigrated with the very high estimate of

emigration rate. The assumptions about the pattern of effort in these seem critical. The exponential patterns used for survival and emigration mean that the most obviously problematic effect would be if the change in effort through time differed between regions. It would be possible to generate simulated data containing different patterns and biases, but the most likely outcome would be a finding that the direction and level of bias depended on the additional patterns.

Overall, while it could be argued that the estimated survival rates are more likely to be under-than over-estimates, there seems no immediate reason not to centre the prior on female pup survival on the point estimate given by Hall *et al.* (2009). The appropriate level of precision to use seems less clear. The various issues mentioned above, and the interannual variability identified by Pomeroy *et al.*, suggest that the distribution should be widened beyond that identified by Hall *et al.* for their data, but not how much that should be done by.

Alternatively, the approach taken by Harwood and Prime could be followed and pup survival derived from adult survival, fecundity, age at first breeding and the exponential population growth rate. Rather than putting a prior on pup survival, it might then be more efficient and consistent to then include a prior for the growth rate as part of the population model and derive a low-density pup survival from each set of parameter values used. That would however ignore the data in Hall *et al.* (2009). The steady population growth in the early 1980s also already has the effect of tuning the demographic parameters to the exponential rate.

Survival of juveniles

Summary

The grey seal population model currently only considers females and simply scales up by 1.73 to convert to total population estimates. It assumes annual survival rates are constant for non-pups, though there is little solid data available to determine whether the survival rate of animals aged 2-5 really matches that of adults.

Tasks identified in 10/04/12 meeting:

- Need to look at juvenile 2-5 yr old survival (Bowen et al 2007 paper).

Provenance of current estimate

A belief that by the end of their first year of life seals have basically learned how to forage.

Available Data

Schwartz and Stobo (2000) study on Sable Island.

By looking at resightings of breeding females that had been branded as pups in 1985, they estimated survival to age 4 at 0.83 (SE=0.04). Similar estimates for pups born in 1986 and 1987 were slightly lower (0.77; 0.70) but those authors suggest that these will have been biased downwards by the termination of the study before all the animals had recruited into the breeding population. If anything, their estimate is higher than the values currently used for first-year survival, and therefore gives no indication that juvenile survival is lower than adult survival.

Age of first calving

Summary

The State Space model assumes that at all females recruit at age 6, after which they have the same constant fecundity. The data on which that is based seems clear.

Conclusions from 10/04/12 meeting:

- Most people agreed that currently used age seems OK
- IOM & NR data is difficult to reconcile with it
- need to include Bowen et al 2007 paper (now included here).

Provenance of current estimate:

Harwood and Prime (1978) used sections cut from teeth to age animals and identify age of first pregnancy. They said: “Sixteen percent of the females shot in the two samples had their first pup at age 5, 45% at age 6 and 39% at age 7 or over”. Their sample included almost 1000 animals.

Other evidence of age at maturity:

Hewer (1964) examined the gonads of 93 female grey seals and concluded that “half the cows become mature at four years of age and the rest at 5”. His sample contained 5 three year olds, 8 four year olds, 5 five year-olds and 6 six year olds.

Boyd (1985) assessed maturity of 183 female grey seas by examining their reproductive tracts and stated: “By the age of four years and over (4+), i.e. at maturity, 50% of females became pregnant. Pregnancy rate remained constant from age 5+ onwards". He commented that these values were one year younger than those in Harwood & Prime.

Hammill and Gosselin (1995) estimated age at first pupping at 5.5 +/- 0.12 yr based on 526 Canadian grey seals.

Bowen *et al*. (2006) watched branded live individuals on Sable Island between 1983 and 2005, while that population was growing. They found:
Of the 82 primiparous females, 30-5% were 4 years old, 57-3% were 5 years old, 9-8% were 6 years old and 2-4% were 7 years old.

Bowen *et al.* (2007) reported:
Females from the 1998–2000 cohorts were about 16 times less likely to give birth for the first time at age 4 yr and more than twice as likely at age 6 yr compared to those in the mid-late 1980s.
However all the animals they reported on first gave birth at age 4, 5 or 6 and the overall increase is from a mean age of first reproduction of 5.01 years in 1985-1989 to one of 5.42 in 1998-2000.

Schwartz and Stobo (2000) also looked at branded animals at Sable and estimated mean age at first pupping at 5.2 years (SE 0.06). These animals were born in 1985-1987 and included some considered in the other Sable studies.
Øigård *et al.* (2012) report very similar values for grey seals in Norway and Iceland.

(It should be noted that Canadians age seals differently, so 1 year needs to be added to convert these to UK seal ages.)

Pomeroy *et al.* (2010) looked at the age at which animals tagged as pups on the Isle of May were first resighted as adults at that colony. They saw 88 out of the 863 animals that were tagged between 1990 and 1997. The mean age at which they were first resighted was 9.4 years (95% CI: 8.8-9.9), with no difference detectable between 1990-1992 and 1993-1997. They got a very similar result for the 18 out of 731 pups tagged between 1978 and 1994 on North Rona that they resighted as adults. The annual probability of resighting tags is critical to the interpretation of these results: if it is close to 1 there is a clear mismatch with the other data, if it is below 0.25 (similar to the value Smoult *et al*. (2011) reported for the Isle of May), then the expected delay in resighting animals is at least 3 years and there is no discrepancy.

Conclusions
Most of the historical data, including the Canadian data, suggest that maturity at age six is about right. However, the Isle of May resighting data would also be consistent with a later age of recruitment, providing the probability of resighting tagged animals was high during that study.

Fecundity

Summary
The population model currently uses Beta(22.05,1.15) as the prior on fecundity. This is the same prior as is used for adult female survival and gives a mean of 0.95 and sd of 0.04. That distribution gives a long lower tail and puts a lot of the probability mass very close to 1. This document suggests that it might be appropriate to modify the prior for this parameter in the model so that it covers a smaller range but is more symmetric and less informative. Unpublished data from the long-term studies on Rona and the Isle of May is not used here, and a way will need to be found to add that in.

Conclusions from 10/04/12 meeting:

- Agreement to change the prior to a shifted and scaled beta(2,2) supported on [0.72,1] (shown in black in Figure 2).*
- If fecundity really differs between areas and years that could affect the abundance estimates. Including such an effect would require modification of the model and depend on the identification of sufficient data to parameterise it.

* This distribution has now been modified to ensure consistency with unpublished SMRU data.

Provenance of current prior
The mean of the prior appears to have been taken from the Farnes samples analysed in Boyd (1985). The skew shape is then a consequence of having a beta with a high variance combined with a mean near one end of the supporting interval.

Available datasets

Hewer (1964) assumed that the pregnancy rate was 0.8 because that was the rate for "the Northern fur seal cow". Hewer (1974) gives two estimates for pregnancy rates: 38/41=93%

from samples in March-July and 42/64=66% if January and February samples are also included. He says that pregnant females are largely absent at sea in the winter, but explains that in terms of them regaining condition they lost "in the previous lactation" and favours a pregnancy rate around 80-85%..

Harwood and Prime (1978) refer to papers on other pinniped species that estimate fecundities in the range 0.8-0.95 and suggest that a value of 0.9 for fecundity is consistent with the then population growth rate, an adult survival of 0.93, and juvenile survival being lower than adult survival.

Hammill and Gosselin (1995) examined 526 Canadian grey seal carcasses. They said:
No trend over time was observed in mean age at first birth or in pregnancy rates. Pregnancy rates determined from reproductive tracts containing a fetus were 0.18, 0.86, and 0.88 for animals aged 4+, 5+, and >6+ yr, respectively. Pregnancy rates calculated from the presence of a corpus luteum were 0.01, 0.45, 0.9, and 1 for ages 3+, 4+, 5+, and >6+, respectively.

Øigård *et al.* (2012) estimate the fecundity of adult grey seals in Norway at 0.81, and report slightly higher values from Iceland.

Boyd (1985) examined animals sampled outside the breeding season and found that 132 out of 140 from the Farne Islands were pregnant, giving an overall rate of 0.94 (95% CI: 0.89-0.97). For the Hebrides the figures were 73 out of 88, giving a rate of 0.83 (95% CI: 0.74-0.89). There is a statistically significant difference between these two estimates (Fisher test, p<0.01),

The results of long-term observational studies suggest somewhat lower fecundity rates. Pomeroy *et al.* (1999) looked at pupping histories of branded females on North Rona. They generated:
a minimum estimate for birth rate at N. Rona of 0.805 within the marked population (minimum number of pups produced/number of pupping opportunities for extant animals = 387/481)."

The probability of getting this result from independent draws from a binomial distribution, with a probability of success in each trial that is below 0.77, is less than 0.05. Those authors also stated:
There were 12 definite cases when branded females returned to North Rona and remained ashore for between 1 and 54 days without pups or showing any sign of having given birth. We are sure that these females did not rear pups in these cases. Reasons for this may include miscarriage, stillbirths or simply not being pregnant on arrival at the rookery. If these were the only nonparous cases in the study the upper limit to our estimate of natality would be (469/481) = 0 975.

Data collected during SMRU's long term studies on North Rona and the Isle of May (P. Pomeroy, *unpubl. data*.; Smout *et al*. *in prep*.) now suggests lower fecundities than the previously estimated values (table 3). The fecundity of each female in the study was estimated by subtracting one from the number of pups she was observed with, then dividing this by the number of years between the first and last pupping occasions recorded. The estimate for each island is the mean of the observed fecundities on it, and the confidence intervals were generated by non-parametric bootstraps with mothers as the unit of resampling. For North Rona, the estimates were corrected for the lack of fieldwork on that island in 1982-1984 and 1990-1992. The overall estimate was constructed from the means of the island estimates.

Table 3: Minimum fecundity estimates, based on observed births to known mothers. The sample columns contain the total number of pups included in the calculations and the maximum number of pups consistent with the observed first and last pupping dates recorded for each mother.

Island	All data		Up to 2003		From 2004	
	Sample	Fecundity	Sample	Fecundity	Sample	Fecundity
North Rona	1034 /1551	0.72 (0.69-0.74)	392 /569	0.77 (0.72-0.80)	484 /675	0.73 (0.70-0.77)
Isle of May	715 /1193	0.63 (0.59-0.68)	380 /638	0.64 (0.58-0.69)	269 /410	0.71 (0.65-0.76)
Both islands	1749 /2744	0.68 (0.65-0.70)	772 /1207	0.70 (0.67-0.74)	753 /1085	0.72 (0.69-0.75)

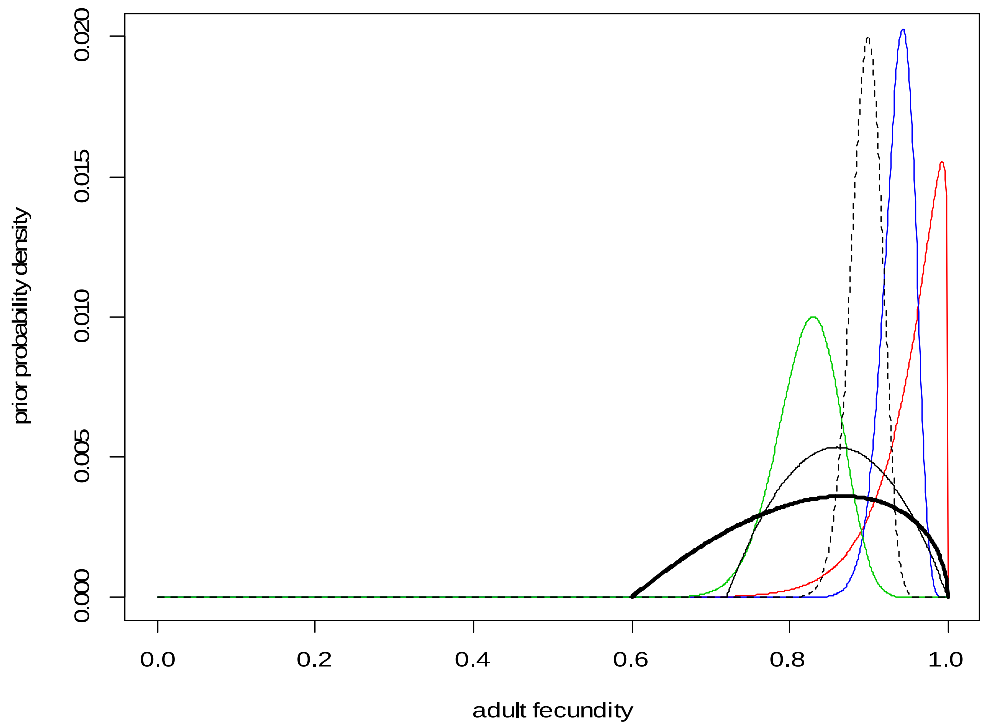
Any births to these females during this period that were not observed will bias these estimates downwards. While it seems unlikely that animals giving birth within the study area would be missed, it is possible that some of them have occasionally pupped elsewhere on the islands or at other colonies. Estimation of the extent of such a bias is likely to be be difficult.

Bowen *et al*. (2006) watched branded live individuals on Sable Island between 1983 and 2005, while that population was growing. They estimated apparent fecundity at 0.73 (SE=0.015, n=174) for animals aged 4-15; 0.83 (SE=0.034; n=32) for ages 16-25 and 0.57 (SE=0.03; n=39) for 26-35 year olds. They stated that they thought any downward bias from not detecting animals that bred elsewhere in some years was likely to be small.

There are three plausible explanations for the lower fecundity rates suggested by long-term observational studies: (i) females breed at other colonies during those years they are not observed within the studies (ii) some females present at the study colonies are not detected (iii) not all pregnancies are brought to term (and these are recorded as pregnancies in studies of ovaries/teeth).

Combining the two Boyd datasets would give a distribution centred on 0.9 (95% CI: 0.85-0.93). The differences between the various estimates suggests it might be overly precise. A shifted and scaled beta(2,2) supported on [0.72,1] would be symmetric and have a 95% CI running from 0.75-0.97, so covering the central 90% of each of the two separate estimates based on the data from Boyd (1985). This is consistent with most of the other estimates. To cover the possibility, raised by Smout (*in prep*), that the true value is lower the range of the prior was widened. A shifted and scaled beta(2, 1.5) supported on [0.6,1] was therefore chosen. It has a mean of 0.83 and 95% confidence interval running from 0.65 to 0.98. Figure 2 shows these distributions.

Figure 2: Possible priors for fecundity. Red is the current prior, blue is from Boyd's Farnes data, green is from his Hebrides data, the black broken line is the result of pooling the two sets of Boyd data. The thin black solid line attempts to cover the bulk of the range of the two Boyd datasets with a symmetric prior. The thick black line is the suggested prior for fecundity.



Conclusion:
If the mismatch between the two estimated pregnancy rates from on Boyd's studies indicates a persistent difference between the two areas, that would need to be incorporated into the model. If it is a result of the variability of samples, then it just suggests a need for a lower precision than that estimated separately for either of the two sets of samples. It is also unclear why the data from the long-term studies of Isle of May and North Rona resulted in lower estimates of fecundity than most of the other studies.

Adult (female) survival

Summary
The population model currently uses Beta(22.05,1.15) as the prior on adult survival. This gives a mean of 0.95 and sd of 0.04. But it gives a long lower tail and puts a lot of the probability mass very close to 1. This document revisits old data, mostly collected by SMRU, and suggests that it might be appropriate to modify the prior for this parameter in the model so that it covers a smaller range but is less informative within it.

Conclusions from 10/04/12 meeting:

- Agreement to change the prior to a shifted and scaled beta(1.6,1.2) supported on [0.8,1] (shown as a broken blue line in Figure 4).

Provenance of current prior
The basis of the current prior is data from two large culls of animals in the Farne Islands (544 females shot in 1972 and 482 shot in 1975 during the breeding season). The data was presented in (Harwood and Prime 1978) , where the annual survival of adult female grey seals was given as 0.935-0.94. Figure 3 below is redrawn from that paper to show the data.

Clearly there is a problem with the under representation of the youngest age groups.

There had been previous pup culls in 1963-1965, so Harwood and Prime excluded animals under 10 in fitting to the 1972 data and under 14 in 1975. Their analysis seems to have been a regression of the log of the numbers of animals of each (integer) age against age. It therefore excluded unrepresented age classes (35 in 1975 and those over the maximum observed age). Their results matched those previously produced from a miscellaneous set of samples (Hewer 1964).

Harwood & Prime pointed out that it was necessary to make a correction because grey seal pup production had been growing. This rate was around 7% pa during the 1960s and early 1970s (Summers 1978), so they converted the slopes of their regressions into annual survivorships by adding 0.07 before exponentiation.

The same data was also used in a population model described within a report to DAFS on grey seal interactions with fisheries (SMRU 1984). That analysis simultaneously estimated all the demographic parameters and the population growth rates for the Farne Islands from the cull data combined with data on fecundity and pup production estimates. It seems to follow Harwood and Prime in considering only the cohorts born in the years of the pup culls to have been affected by them. Possible displacement of animals reaching maturity near the time of the culls was not considered in either analysis. Annual survival of adult female grey seals was estimated at 0.95 or 0.98 depending on the details of the assumptions used.

Harwood and Prime state: *animals were not taken representatively from each of the four major islands in the Farnes' group. The average age of females differed significantly between islands, so the age structure for each island was weighted in proportion to the number of pups born on that island in the year before the cull. These weighted distributions were then combined to give an age distribution for the entire stock.*

The DAFS report states: *the large culls of 1972 and 1975 did not take representative samples of the population. This is because the numbers of seals taken on each island were not in proportion to the size of the population on that island, and the average age of seals is not the same for each island. The age structures of these culls have been processed to give random samples of the population age structure in those years for animals above the age at which they appear to be fully represented in the culls.*

If these are descriptions of the same process, then it would seem that the regressions Harwood and Prime carried out and plotted were not of the raw data. There is also a potential issue in that the primary aim of the culls was to reduce the population and impacts on nesting seabirds rather than obtain random samples. It is likely that the most accessible animals, or those in areas of particular interest for seabird conservation, were targeted. Structure within the breeding colony could make such samples unrepresentative.

The most obvious issue highlighted by re-examination of this data was the effect of the threshold chosen for cohorts to be considered undisturbed. Visual inspection suggests that the cohorts that would have recruited around the times of the pup culls may be under-represented. Excluding these from the analysis reduces estimated adult survival rates. There is also a secondary issue with fitting a regression to the data in that a decision has to be made as to how many empty age-classes should be appended to the data.

Mathematical limits on the range of values possible for adult survival.

If it is accepted that female grey seals have no more than 1 pup each year and half of those are male, then even assuming every female has a pup every year of its life and there is no pup mortality, then mortality rates on female adult grey seals cannot be above 50% pa without driving the population to extinction.

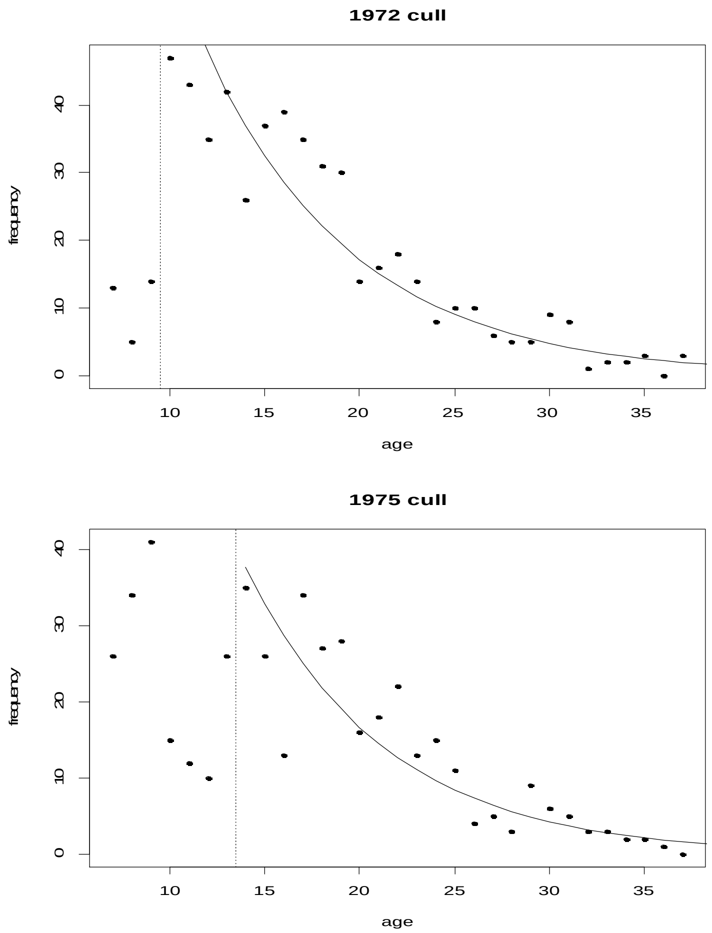
This threshold is raised if the slightly more realistic assumptions are made that pup survival is no higher than adult survival and females first pup at age 4. Then:

$$1\text{-p} = 0.5 * \Sigma_{i=4}^{\infty} p^i \; / \; \Sigma_{i=0}^{\infty} p^i$$

Or: $1\text{-p} = 0.5 * p^4$

Which gives a lower bound of 0.8 for p, the annual survival rate, if the population is to persist. This lower bound is quite conservative, since the overall UK population of grey seals increased greatly over the 20th century (Summers 1978; Lambert 2002; Lonergan, Thompson et al. 2011), despite continuing

Figure 3 Age structure of females culled in the Farne Islands in 1972 and 1975 (redrawn from Harwood & Prime 1978). Continuous black lines are those authors' fits to the datapoints that lie to the right of the vertical dotted lines.



killing of individuals in many areas over much of that time. Allowing for a maximum population growth rate of 12%pa would increase this lower bound to 0.845. Using the 7% growth rate reported from the Farne

A uniform distribution running from 0.8 to1 produces a prior that looks quite different from the one currently used for this parameter (figure 4). It has a lower mean (0.9 against 0.95) and a higher variance (0.0033 against ry close to 0.8.

Islands (Summers 1978) would put the bound at 0.825. Fecundity is certainly less than 100%, which would further raise this limit, and there is also good evidence that pup survival is considerably lower than adult survival.

0.0016). It is arguable whether the uniform representation would really be sufficiently uninformative to use for this prior without the data discussed below.

F

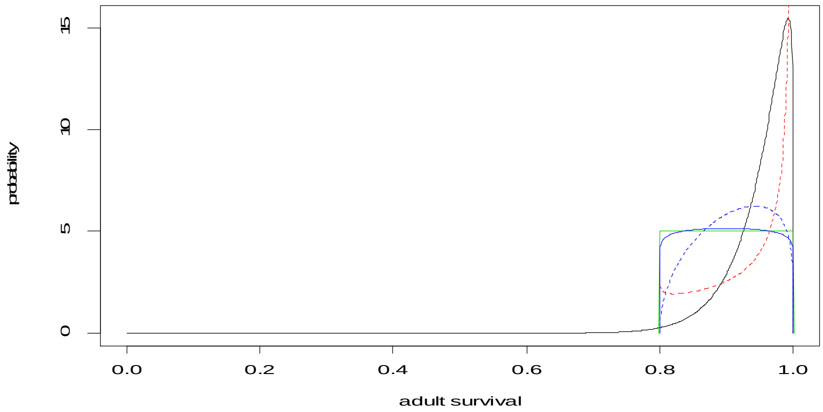


Figure 4: current prior on grey seal survival (black line) compared to a uniform distribution running from 0.8 (a conservative lower bound on possible values of this parameter) to 1 (green line). The blue line is a scaled Beta(1.05,1.05) which provides a slightly rounded-off version of the uniform distribution. The red broken line is a bizarre scaled beta on [0.8, 1] that matches the mean and variance of the current prior. The broken blue line is a scaled Beta(1.6,1.2) which might be considered as a way of reflecting a belief that adult survival is unlikely to be –ve

Methodology used in the re-examination of datasets

GLMs with log links and Poisson errors can be used to estimate survivorship, but these require the addition of trailing zeros in unrepresented age classes to avoid biasing their results. Binomial GLMs giving the proportion of the total sample in each age class reduce that problem but introduce interdependencies between the datapoints. Another way to sidestep the trailing zero problem might be to discard all data beyond an arbitrarily chosen upper age, though that threshold would have to be selected independently of the ages of the data sample.

Instead a direct maximum likelihood approach was taken. The probability that the age of an animal that was at least a years old and drawn from a population growing at an annual rate g and with annual survivorship s was age x was taken to be:

$$p(x|s,a,g) = \left(s^{x-a}/(1+g)^{x-a}\right) \Big/ \Sigma_{i=0}^{i=\infty}\left(s^{i-a}/(1+g)^{i-a}\right)$$

Essentially the first part of the numerator represents adult survival and the second represents the exponential growth of pup production through the previous years. There is no explicit assumption about the stability of the age structure of the population during this period. The denominator provides a normalising constant. Reducing the upper bound on the summation allows the equation to be used for truncated datasets.

Each model was fitted to subsets of the datasets that cropped various numbers of age classes off the tails of the age distribution. The survival rate was estimated for each subset of data with the R function *optimise* with the population growth rate generally set to 7% pa.

Effectively this description estimates $\frac{s}{1+g}$ and therefore it is not possible to fit both s and g simultaneously, but it can be seen that a one percentage point increase in population growth rate will approximately correspond to a 1% change in adult survival. 100 non-parametric bootstrap replicate datasets were used to estimate confidence intervals around each estimate.

Refitting to data from Harwood and Prime (1978)

I extracted the data from figure 3 in Harwood & Prime to re-examine the prior (data is in table 4) and estimated survival rates for each cull separately and also the combined data from the two culls.

It seems clear from Figure 5 that 0.95 is quite a high value for the mean of the prior on adult survival unless the population growth rate was quite a bit lower than 7% or the youngest age classes are included. There does not seem to be a simple step change indicating an age beyond which there can be considered to be a stable exponential pattern. To examine whether the changes in estimated survival rates are due to increased mortality in older individuals the equivalent rate of exponential decay was re-estimated for subsets of the data truncated at both ends

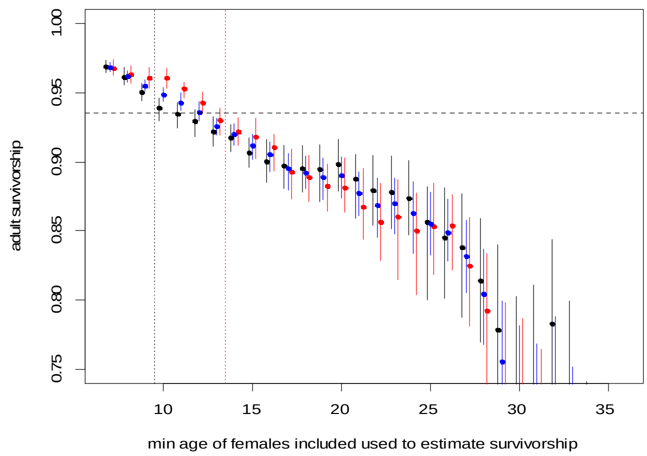


Figure 5: Estimates (mean and 95% bootstrap confidence intervals) of the annual survivorship of adult females based on subsets of the data (1972 cull =black; both = blue; 1975 cull =red) starting at different ages. The horizontal black line is the 93.5% survivorship suggested by Harwood and Prime (the current prior is centred on 0.95). The vertical dotted lines are the lower age thresholds used by those authors in analysing the data.

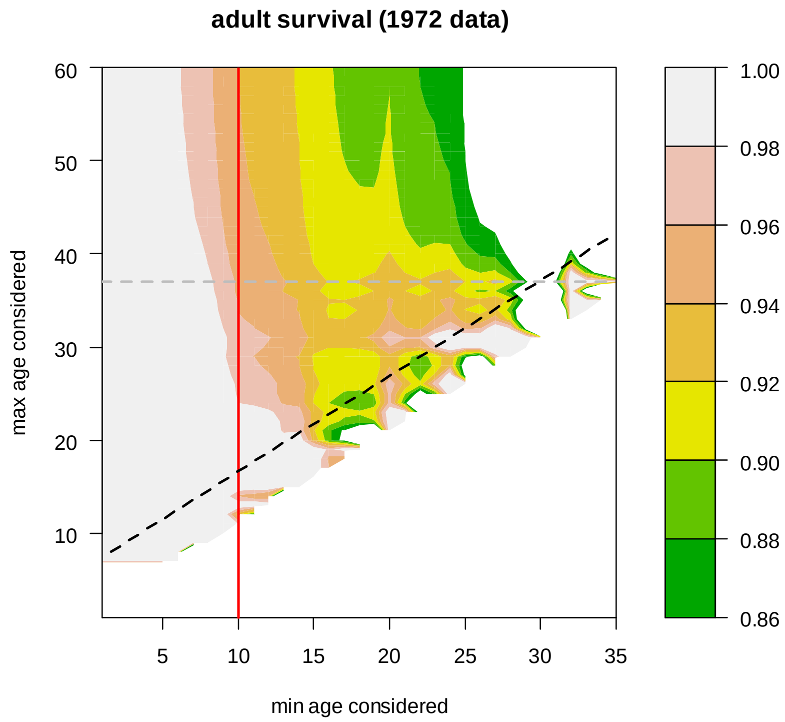


Figure 6: Estimated annual survivorships from 1972 cull data. At each integer location (x,y) the estimated survivorship based on sampled animals aged from x to y years is plotted. The surface is interpolated using R function filled.contour and coloured according to the legend on the right. The continuous red line indicates where Harwood and Prime cropped the data. Estimates below the black broken line are based on 5 or fewer datapoints (because the minimum and maximum ages of animals include are 5 or less years apart) and therefore less likely to be reliable. The horizontal broken grey line is the maximum age of the animals in the sample. The top of the figure provides the values for effectively untruncated upper ages, and the Harwood and Prime estimate lies at the top of the red line.

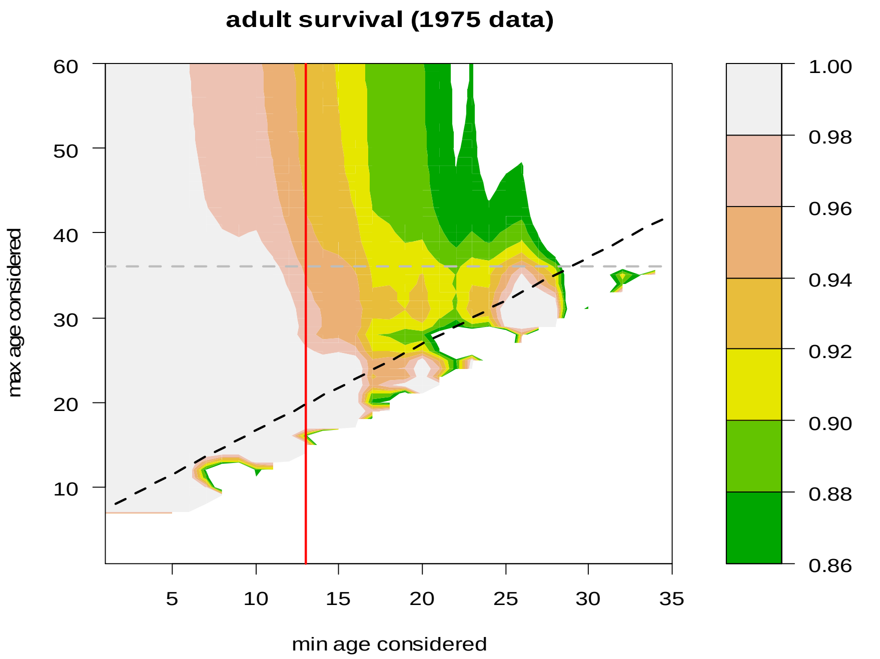


Figure 7: Estimated annual survivorships from 1975 cull data. At each integer location (x,y) the estimated survivorship based on sampled animals aged from x to y years is plotted. The surface is interpolated using R function filled.contour and coloured according to the legend on the right. The continuous red line indicates where Harwood and Prime cropped the data. Estimates below the black broken line are based on 5 or fewer datapoints (because the minimum and maximum ages of animals include are 5 or less years apart) and therefore less likely to be reliable. The horizontal broken grey line is the maximum age of the animals in the sample. The top of the figure provides the values for effectively untruncated upper ages, and the Harwood and Prime estimate is close to the top of the red line.

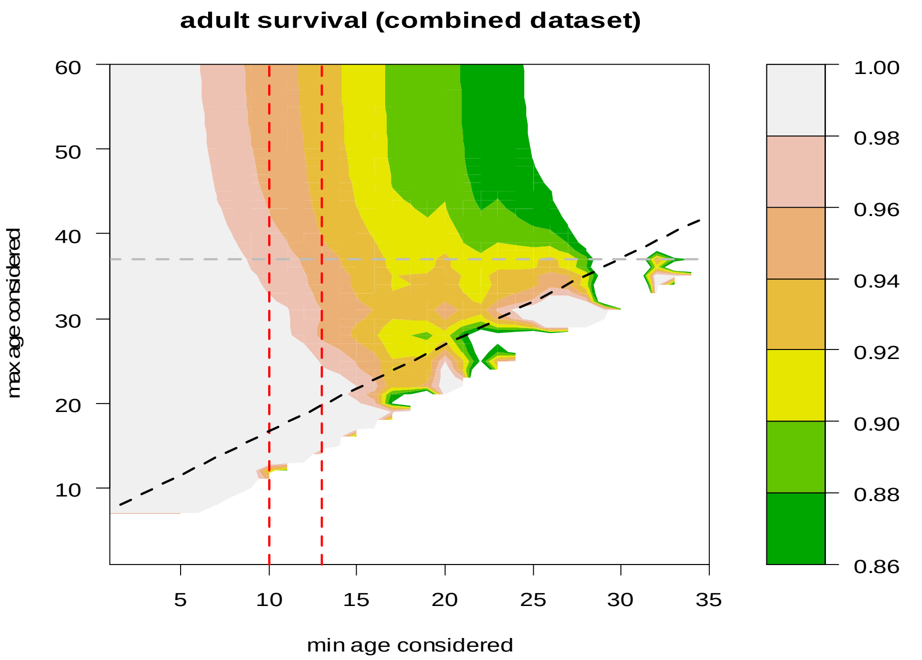


Figure 8: Estimated annual survivorships from combining the datasets from the two culls. At each integer location (x,y) the estimated survivorship based on sampled animals aged from x to y years is plotted. The surface is interpolated using R function filled.contour and coloured according to the legend on the right. The broken red lines indicates where Harwood and Prime cropped the two datasets. Estimates below the black broken line are based on 5 or fewer datapoints (because the minimum and maximum ages of animals include are 5 or less years apart) and therefore less likely to be reliable. The horizontal broken grey line is the maximum age of the animals in the sample. The top of the figure provides the values for effectively untruncated upper ages.

All three plots suggest peak survivorship is around 0.90-0.96. The generally vertical striping across the tops of the figures suggests that the change in survivorship occurs across the all ages of animals.

There are several potential explanations for this patterning:

1) pup production had not been growing exponentially up to 1963
2) the sample does not represent the population because:
   a. it was not randomly selected from the available animals
   b. younger animals are under-represented because recruitment into the breeding population is gradual
   c. the pup culls in 1963-1965 reduced the recruitment of animals born a few years before then into the breeding population
   d. Older animals are under-represented because they breed less often
3) adult female grey seals do not have a constant risk of mortality.

Variation of several percentage points in the rate of growth of the pup production would be necessary for it to explain the variation in the estimated survivorship from the different subsets. An error in the 7% estimate of mean population growth rate would simply shift all the estimates in parallel, and it would seem unlikely that random fluctuations would produce the observed pattern. Instead it would require that the growth rate of the population had decelerated substantially over the years between 1940 and 1963 for explanation 1 to work.

Explanation 2a is difficult to test, and if true could make it impossible to draw any useful conclusions at all.

Figure 5 makes 2b seem unlikely to explain the whole of this pattern – it seems hard to believe that the cohorts are not fully mature and recruited by age 20.

The pup culls of 1963-5 were made at the very end of the breeding seasons and took moulted pups (J. Harwood, *pers. comm*. – the original datasheets are somewhere in the SMRU building). That could be expected to limit their disruptive effect on older animals. The pup production estimates for 1964, 1965 and 1966 aren't obviously below the trend line up to 1971 (Summers 1978). To explain the whole pattern, 2c would also require that the pup culls permanently displaced substantial numbers of even 20 year old animals, with this effect gradually reducing through the age-classes. That is possible, though it might have been expected that disruption would have a stronger effect on the newly recruiting adults then a consistent effect on all the oldest age classes.

The horizontal pattern around the maximum sampled age could be interpreted as suggesting that this age class may be underrepresented compared to what might be expected from an exponential distribution. However the estimated survival rate falls off again as the oldest animals are excluded (in the area around/above the broken diagonal black line in figures 6-8). That could not be a result of 2d.

A combination of 2c and 2d could cause the whole pattern, but is hardly parsimonious.

Non-exponential survival, explanation 3, could also explain the pattern. However it would seem to suggest that the survival rates for this set of animals were highest between about ages 18 and 33. Those values seem surprisingly high given the observed ages of the samples.

The grey seal model represents the longevity of adult females as following an exponential distribution, so a suitable exponential decay rate would be needed to represent any non-exponential mortality schedule. Figures 5-8 suggest that using the data in Harwood and Prime requires a decision as to where to crop that dataset, with each year added to the threshold reducing the estimated annual survival rate by 0.5%.

Re-examination of other datasets

There are two other systematic datasets containing large numbers of grey seal ages from the UK. There is also the collection of miscellaneous data in the green cardfile. Each of these is described below. They are followed by a brief summary of the survival estimates reported in Smout *et al.* (2011) for a mark-recapture model of resight data from North Rona and the Isle of May.

Data from Hewer

Hewer aged teeth from 239 female grey seals. Data from 123 were reported on in a paper (Hewer 1964) that put forward an “empirical life table” based on that for “the Northern fur seal cow”. The samples came from various sources and he estimated annual mortality at 6.7%. He did not mention the relevant population growth rates, or say anything about correcting for it.

He described the full dataset in a book (Hewer 1974), which said of the data’s collection:

"During the years 1956 to 1966 specimens were collected, some from the normal practice of fishery protection, some specifically shot for research purposes. Generally speaking there has been no attempt at selective collection so that, other things being equal, the collection is a fair sample of the population available."

Table 4 and figure 9 include the full Hewer dataset.

Figure 9: Age distribution of females in Hewer's sample:

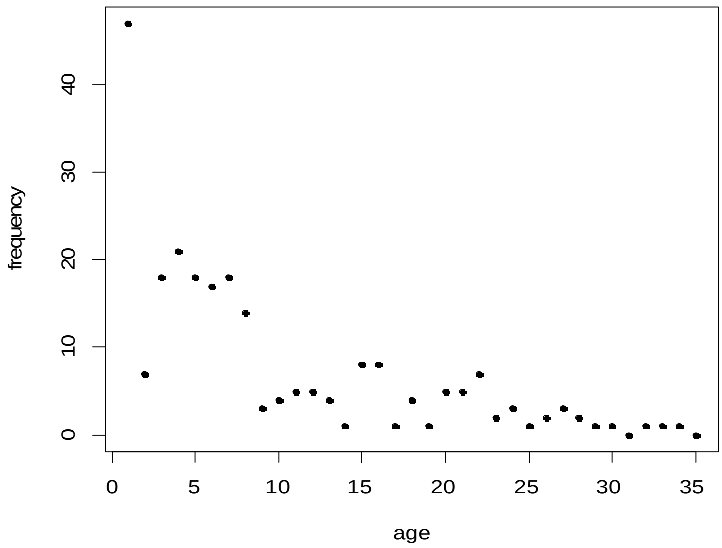


Figure 10: Estimates (mean and 95% bootstrap confidence intervals) of the annual survivorship of adult females based on subsets of Hewer's data based on different assumed pup production growth rates (7% pa =black; 3% = blue; stable pup production =red) starting at different ages. The horizontal black line is the 93.5% survivorship suggested by Harwood and Prime (the current prior is centred on 0.95).

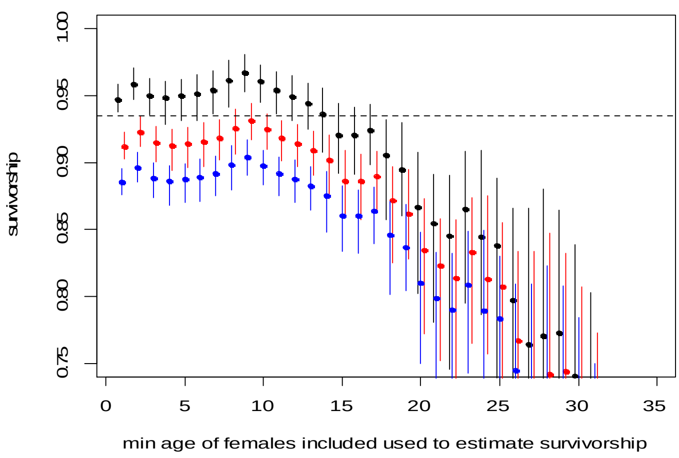
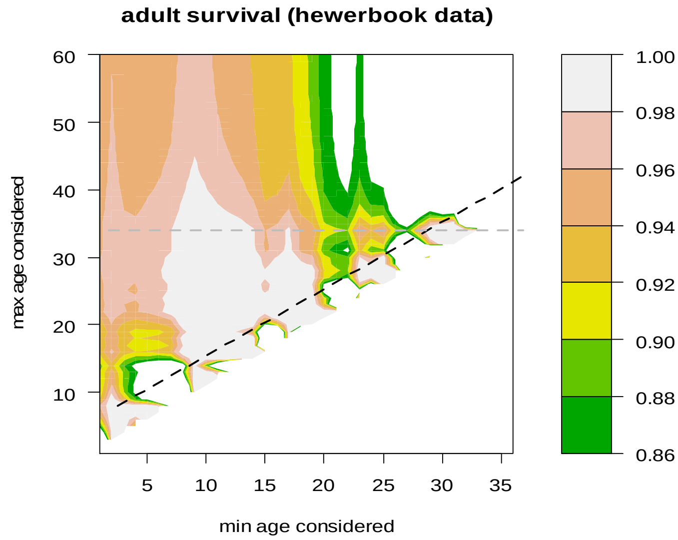


Figure 11: Estimated annual survivorships based on the Hewer dataset with an assumed population growth rate of 7%pa. At each integer location (x,y) the estimated survivorship based on sampled animals aged from x to y years is plotted. The surface is interpolated using R function filled.contour and coloured according to the legend on the right. Estimates below the black broken line are based on 5 or fewer datapoints (because the minimum and maximum ages of animals include are 5 or less years apart) and therefore less likely to be reliable. The horizontal broken grey line is the maximum age of the animals in the sample. The top of the figure provides the values for effectively untruncated upper ages.



The estimates for each population growth rate are remarkably stable up to age 15. The patterns are effectively offset from each other by the differences in assumed growth rates in pup production.

If Hewer's sample can be considered representative and comes from a population growing at 7% pa, it seems to imply that the annual survival rate for adult female grey seals is likely to have been around 95%. If that population was growing more slowly, it would imply lower survival rates. This data avoids the problems of fecundity affecting the age classes available for sampling at breeding colonies and is likely to be less sensitive to the effects of short-term culling or other impacts on small numbers of cohorts. It is suggestive of the oldest age-classes being under-represented relative to an exponential pattern.

b) Data from Ian Boyd's PhD study 184 female grey seals were collected in the Farnes between 1978 and 1981 and aged as part of Ian's PhD study. The sampling strategy was aimed at getting a cross-section of the animals present at the breeding colony. Some aspects of this data are unpublished. The major difficulty in estimating annual survivorship from this data is the after effects of the 1963-5, 1972 and 1975 culls.

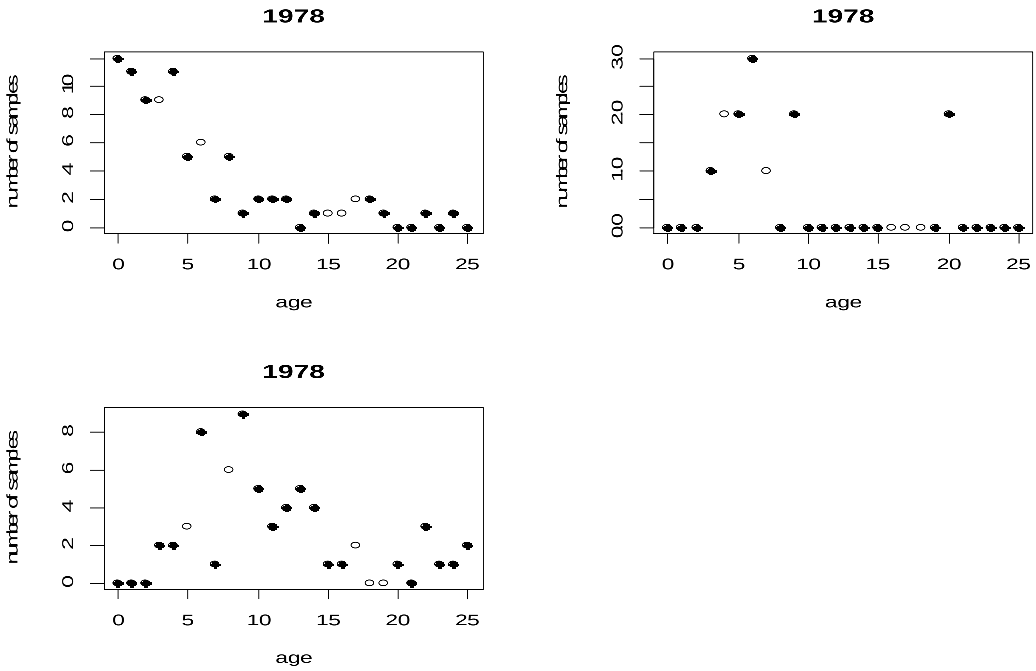


Figure 12: Age distribution of samples from each year. Hollow points are cohorts born during cull years.

Figure 12 suggests that the various culling episodes are likely to make it quite difficult to use this data to establish the age structure/annual survivorship of an undisturbed low-density population. It would require a model of total population size and fecundity, to estimate the direct effects of culling adults, combined with some way of representing the disruption and emigration of survivors of culls.

c) Green Cardfile data This contains data on various dead animals that SMRU has taken samples from. There are 78 female grey seals recorded in it, collected during the 1970s and 1980s, for which ages were estimated. Some of these were also part of the other datasets described above. Some of the animals were deliberately killed, either for samples or for other reasons, while others were found dead. A few died during what were intended to be non-lethal scientific investigations. Table 4 and figure 13 show the age distribution of these animals.

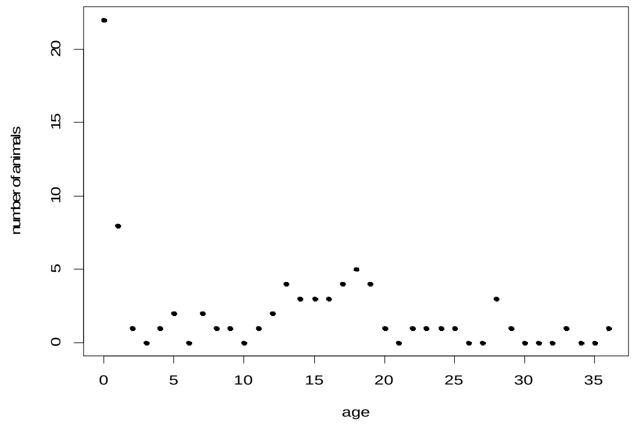


Figure 13: Age distribution of female grey seals recorded in SMRU green cardfile.

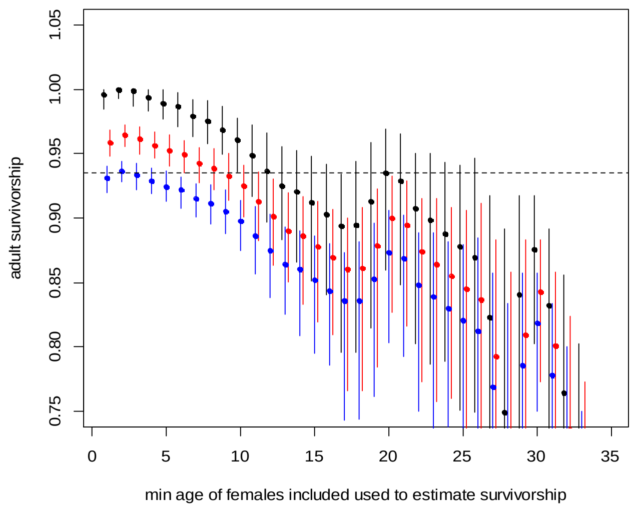


Figure 14: Estimates (mean and 95% bootstrap confidence intervals) of the annual survivorship of adult females based on subsets of the cardfile data based on different assumed pup production growth rates (7% pa =black; 3% = blue; stable pup production =red) starting at different ages. The horizontal black line is the 93.5% survivorship suggested by Harwood and Prime (the current prior is centred on 0.95).

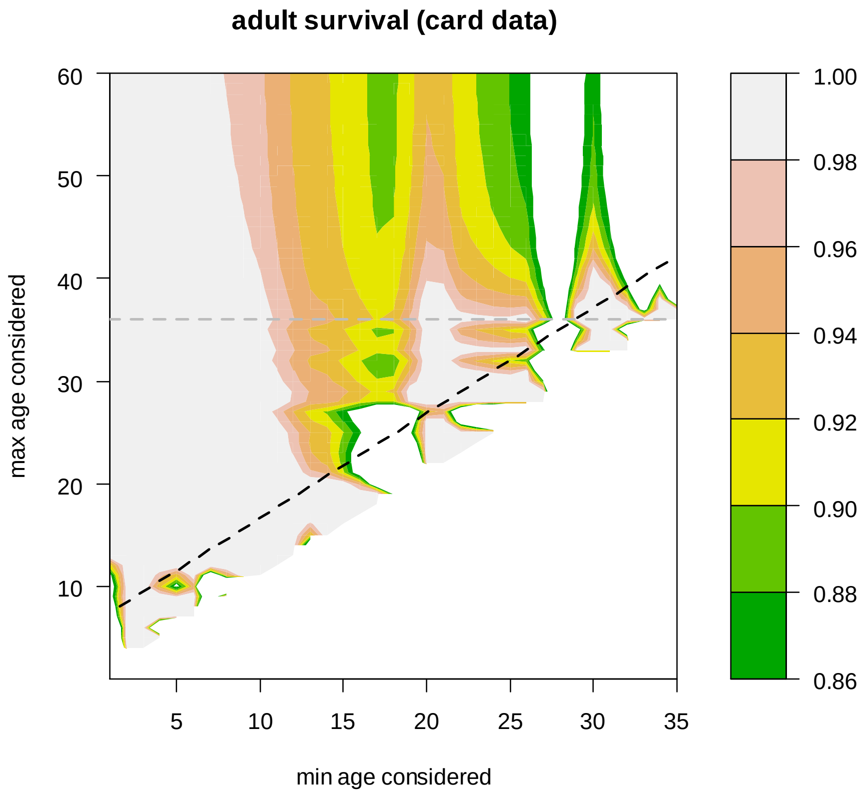


Figure 15: Estimated annual survivorships the cardfile dataset with an assumed population growth rate of 7%pa. At each integer location (x,y) the estimated survivorship based on sampled animals aged from x to y years is plotted. The surface is interpolated using R function filled.contour and coloured according to the legend on the right. Estimates below the black broken line are based on 5 or fewer datapoints (because the minimum and maximum ages of animals include are 5 or less years apart) and therefore less likely to be reliable. The horizontal broken grey line is the maximum age of the animals in the sample. The top of the figure provides the values for effectively untruncated upper ages.

This dataset does not seem to provide much information to determine adult survivorship, since the distribution of ages is far enough from an obvious exponential to allow almost any conclusion to be reached through careful selection of age-classes for inclusion.

d) **Pomeroy *et al.* (1994) data from North Rona**

This paper reports that 62 out of 67 (93%) of adult female grey seals, branded at the breeding colony in 1985, were resighted in later years. This data was also used in Smout *et al.*(2011).

e) **Smout *et al.* (2011) model of North Rona and Isle of May resight data.**

From a Bayesian model that represented tag loss and different observabilities for branded, tagged, and naturally marked adult female grey seals Smout *et al*. concluded:

Survival probabilities for NR were more variable and generally lower than at IoM. Overlap between the 95% credible intervals for survival probabilities at IoM suggests a constant survival probability for this colony, estimated at 0.974 (0.966, 0.981).

…

For NR (where survival was time-dependent) we calculated a posterior estimate of 0.89 for the geometric mean survival probability.

It should be noted here that these are estimates of 'apparent' survival rate, so that 'death' here is confounded with permanent emigration from the colony. True survival rates for animals from these colonies could be higher, but should not be lower, than those estimated from the mark-recapture data.

When they refitted deterministic Leslie matrix models to the population dynamics, they found that annual adult survival rates of 0.89 on North Rona and 0.97 on the Isle of May produced pup production trajectories similar to those observed at the two islands. The models of both colonies assumed:

(i) *age structure at both colonies was initially stable and remained fixed;*

(ii) *the age of sexual maturity varied between individuals, following a normal distribution with mean 9.4*

years and standard deviation 2.7 years (Pomeroy et al. 2010);

(iii) survival for pups aged 0–1 year was 0.6 at both sites (Hall, McConnell & Barker 2001; Hall, Thomas & McConnell 2009);

(iv) the number of female pups per female per year at each colony was approximately 0.35 (Smout, Pomeroy & King 2007)

(v) there was no significant migration at either colony.

These two estimates of adult survival lie in the range suggested by other studies, suggesting that this explanation of the difference between the two trajectories of pup production is consistent with the other data that is available. However, by making fecundity and pup survival constant, the model effectively assumes that differences between population trajectories are always a result of differences in adult survival rates. As a consequence, it can provide very little information about the actual variability of adult survival rates. While grey seal population growth rates are very sensitive to adult survival (Harwood & Prime 1978), the assumption that this is the demographic parameter that varies most, between areas or over time, is less obvious.

f) **Schwartz and Stobo (2000) study on Sable Island.**

By looking at resightings of breeding females that had been branded as pups in 1985, they estimated adult survival as 0.92 (SE=0.014). Similar estimates for pups born in 1986 and 1987 were slightly lower (0.91; 0.88) but may have been biased downwards by the termination of the study.

Conclusion:

The Harwood and Prime dataset suggests adult survival lies within the range 86-95%. However the results it produces are not unambiguous. The Hewer data could be tentatively interpreted as suggesting that adult survival was around 92-98%. The interpretation of both these datasets depends on beliefs about the growth of grey seal pup production in the 1940s, a period for which very limited data is available. The question of whether adult grey seals truly follow an exponential mortality curve is of limited relevance to determining population size, because the population age structure changes relatively slowly. It does however complicate the choice of an appropriate exponential decay rate to represent survival.

The theoretical lower bound of 0.8 resulting from the delay until maturity and the lack of twinning is one solid piece of information that ties this prior down. The sustained growth of the UK grey seal population implies that the correct lower boundary is actually a few percentage points higher. The current form of the prior, with most of its probability mass at very high annual survivorships (figure 4), seems to have limited support from these data. A prior distribution that was more uniform across the range of values identified as possibly correct (0.8-1) would seem more appropriate, and would also be consistent with the results of the long-term observational studies. Refining the prior much beyond the uniform would require decisions about how much weight to put on each of the datasets.

Adult survival is the main parameter in the grey seal models that has a posterior distribution noticeably different from its prior (SCOS 2009) (Lonergan, Thompson et al. 2011). With the current prior, it seems to get pulled down to centre somewhere around 91-95% with a confidence interval about 3-4 percentage points wide. That would seem to suggest that the exact shape of the edges of prior may be relatively unimportant, allowing the corners of the uniform distribution to be shaved off to reduce potential numerical problems. A scaled beta distribution, such as Beta(1.05,1.05) running from 0.8 to 1 (figure 4), which has a mean of 0.9, would approximately increase the standard deviation by 40% without some of the more questionable features of the current prior.

Preserving the mean (0.95) and variance (0.0016) of the current prior in a scaled beta distribution on [0.8, 1] would produce a strange, slightly bimodal prior (figure 4). It appears that unless the data is felt to be strongly informative, either the mean or the variance of the prior distribution for the survival of adult female grey seals needs to be reduced. All beta distributions with means at 0.75 (equivalent to a mean of 0.95 when scaled to [0.8,1] are strongly peaked. That would suggest a distribution with a lower mean might be computationally necessary, unless a different family of distributions was used. The three datasets all seem to suggest that the survival rate is unlikely to be much below 0.88, unless the annual growth rate in pup production was well below 7% pa. That might suggest that raising the lower bound might be appropriate, though doing so would impose a hard limit on the model fitting. An alternative would be reduce the mean slightly to allow a flatter distribution, the example of a scaled Beta(1.5,1.2), which has a mean of 0.915 and sd of 0.05 is also shown in figure 4 (broken blue line).

It would be interesting to examine other datasets, but given that the Harwood & Prime dataset contained over 1000 animals and Hewer another 239, it seems unlikely that alternative datasets would produce clear results unless they were very large and contained large amounts of ancillary data about relevant population trajectories. The data pre-processing Harwood and Prime carried out could be revisited, though the only obvious way for that to narrow the prior by much would be to dramatically shift the estimate so that it was compressed against one end of the theoretical range.

The modifications discussed here should remove a slight bias upwards in the current survival estimate and this might speed up the convergence of the population model.

Table 4: Ages of the female seals used in this analysis Cull72 and cull 75 are data extracted from Figure 3 of Harwood and Prime (1978) for the culls in the Farne Islands. Hewer is his full dataset (book) and the subset reported in his 1964 paper. SMRU green cardfile was transcribed from there by me. "-" indicates where there were no animals reported of a young age class but it is unclear whether the dataset had been truncated by the original authors.

Age of animal	Cull 72	Cull 75	Hewer		SMRU green cardfile
			Book	paper	
0	-	-	-	-	22
1	-	-	47	21	8
2	-	-	7	8	1
3	-	-	18	9	0
4	-	-	21	14	1
5	-	-	18	9	2
6	-	-	17	7	0
7	13	26	18	6	2
8	5	34	14	5	1
9	14	41	3	2	1
10	47	15	4	5	0
11	43	12	5	1	1
12	35	10	5	3	2
13	42	26	4	3	4
14	26	35	1	1	3
15	37	26	8	1	3
16	39	13	8	4	3
17	35	34	1	1	4
18	31	27	4	1	5
19	30	28	1	0	4
20	14	16	5	0	1
21	16	18	5	4	0
22	18	22	7	5	1
23	14	13	2	2	1
24	8	15	3	2	1
25	10	11	1	0	1
26	10	4	2	1	0
27	6	5	3	2	0
28	5	3	2	2	3
29	5	9	1	0	1
30	9	6	1	0	0
31	8	5	0	1	0
32	1	3	1	1	0
33	2	3	1	1	0
34	2	2	1	0	0
35	3	2	0	1	0
36	0	1	0	0	0
37	3	0	0	0	0

Summary

The grey seal population model currently only considers females. The total abundance estimate is then generated by multiplying the number of females by 1.73. This document uses published data to suggest a distribution (a shifted gamma, defined as: 1+gamma(scale=0.1,shape=2), which is centred on 1.2) that appears to provide a better representation of current knowledge of this factor and allow the uncertainty in it to be included in the analysis.

Conclusions from 10/04/12 meeting:

- need to reanalyse the three Hall datasets as well as the older flat tag data and the newer telemetry data.
- We didn't properly discuss effects of differential adult survival.
- Need to look at juvenile 2-5 yr old survival (Bowen et al 2007 paper).

Provenance of current estimate

John Harwood said:

I estimated adult male survival from age 10 as 0.8 based on a log-liner regression of the age structure from the 1972 and 1975 Farnes culls shown in Fig. 2 of Harwood & Prime. That does of course make the, probably incorrect, assumption that the cull was a representative sample of the males on the breeding colony, and that those males are a representative sample of the population. I then assumed that male and female survival were identical up to this age, and that female survival was 0.935. A population with these demographic rates sould have a sex ratio of 1:0.73, I think - though I haven't checked the calculation. That was all done before we knew that male pup survival is probably substantially lower than female survival.

(That does give a sex-ratio of 1:0.73 provided the maximum lifespan is set to 35 years. Half of all females and 2/3 of males are then aged ten or less, so even with no adult male survival the minimum sex-ratio would be 1:0.5.)

Data used in these calculations

1) The ages of sampled seals given in Hewer (1974)
2) The pup survival estimates given in Hall et al. (2001).

Data from Hewer

Hewer aged teeth from 239 female and 254 male grey seals. The samples came from various sources and he estimated annual mortality at 6.7%. He did not mention the relevant population growth rates, or their effects. He described the full dataset in a book (Hewer 1974), which said of the data's collection: "During the years 1956 to 1966 specimens were collected, some from the normal practice of fishery protection, some specifically shot for research purposes. Generally speaking there has been no attempt at selective collection so that, other things being equal, the collection is a fair sample of the population available." However he went on to say "There is probably a disproportionate number of yearlings since, although they are naturally the largest single age group, they form a high proportion of those killed and collected on the salmon grounds of the east coast of Scotland."

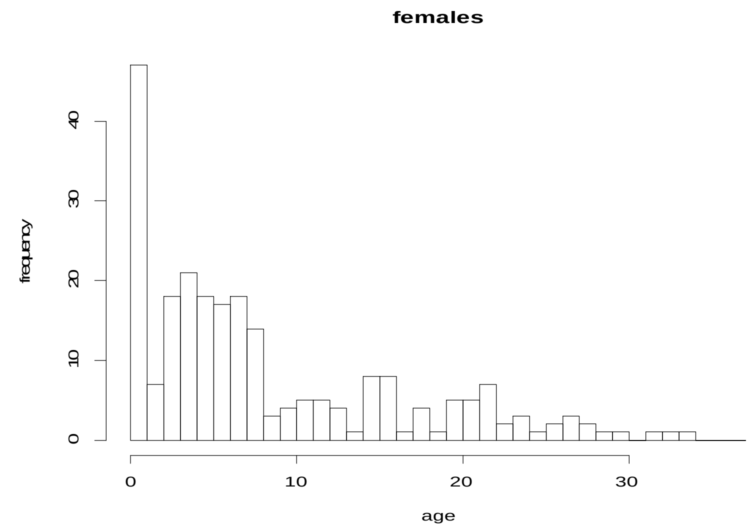


Figure 16: Age distribution of females in Hewer's sample:

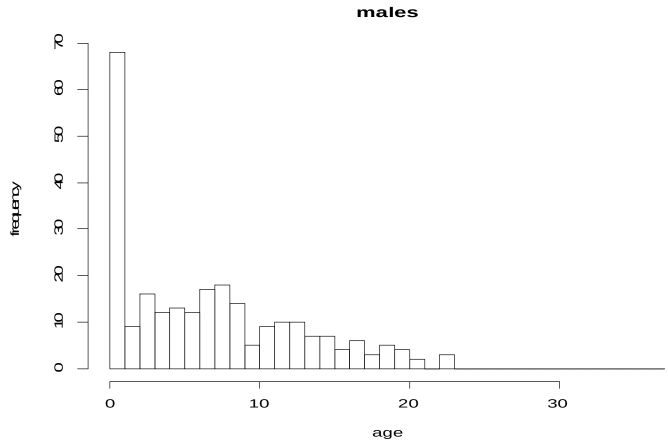


Figure 17: Age distribution of males in Hewer's sample:

The distribution of ages in the female samples appears more consistent with an exponential distribution than that for the males (which, after the youngest animals, seem to indicate fairly similar numbers in each age class) The ages of these animals could be considered representative two different things, either the ages of live animals or the age of death of animals, depending on how their collection is viewed. It is also possible that they adequately represent neither of these.

The 493 animals sampled was around 1% of the total population at that time, so should not have affected the overall age-structure. The samples collected in "the normal practice of fishery protection" might represent the ages at which seals generally died if that were the main cause of mortality in the population. However the large numbers of shootings required, and the steady growth of the population, make that difficult to believe.

For the sex ratio of the samples to be representative of the living population, each of the animals within each age-class in that population needs to have had an equal probability of being sampled. Hewer himself questioned whether that assumption was correct for the youngest animals. Differences in behaviour may also have unbalanced the sampling of other groups within the population and there may have been deliberate selection of animals for inclusion. Examination of Hewer's notes might shed some light on these possibilities, but is beyond the scope of this document.

Ignoring these complications, Hewer's data suggests that there were 254/239=1.06 (bootstrap 95% CI: 0.88-1.28) males per female in the population (Figure 18). Considering each age-group separately (Figure 19) suggests that the youngest age-class probably contains more males than females ($p<0.05$), but gives no reason to rule out an overall sex ratio of 1:1 in this population

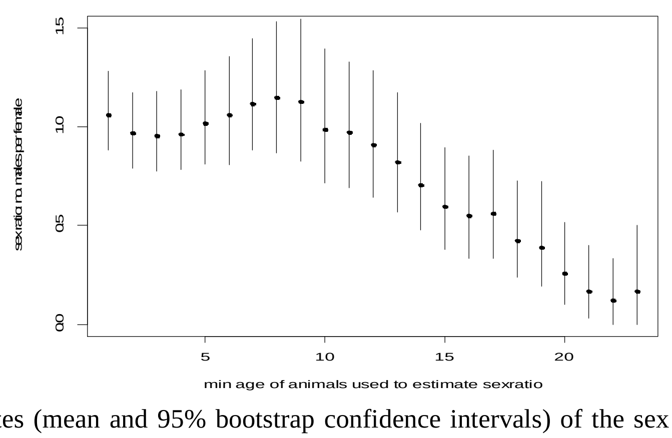


Figure 18: Estimates (mean and 95% bootstrap confidence intervals) of the sex ratio in the grey seal population based on the proportion of males in subsets of the samples above various minimum ages.

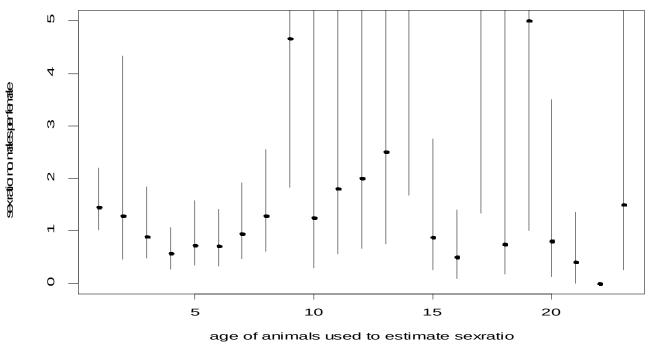


Figure 19: Estimates (mean and 95% bootstrap confidence intervals) of the sex ratio in the grey seal population based on the proportion of males in subsets of the samples of particular ages

As the oldest animals in the samples are female (Figures 16 & 17), this would require that mortality be much higher among young females than males in this population, a conclusion that is hard to reconcile with the results of Hall et al. (2001) and other studies/species.

One way of sidestepping this problem is to assume that the sampling was representative within but not between the sexes. That would allow the sex-ratio of the population to be estimated from the difference in the average ages of the samples of the two sexes. However, this assumption implies a belief that only the differences in appearance and behaviour of the sexes affected sampling, and an explanation of why the similarly clear differences between immature and mature individuals had no effect.

If the pattern of age distribution is similar for both sexes (ie figure 17 is the same shape as figure 16, just with the axes stretched linearly), then the sex-ratio of the population will equal the ratio of the mean ages of the male and female samples (Figure 20).

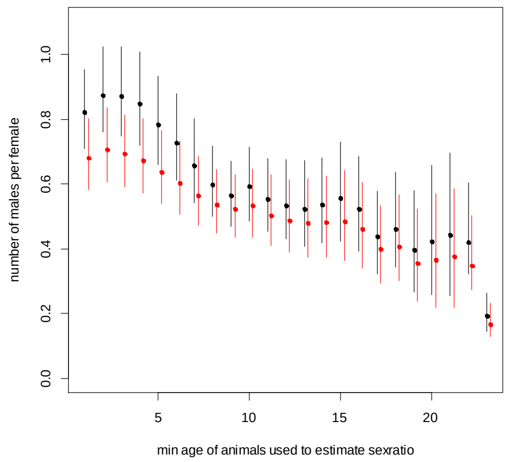


Figure 20: estimated sex-ratios (mean and 95% CI) based on the mean ages of subsets of animals. Each estimate is calculated by taking all animals greater than a minimum age and subtracting that minimum from each one's age before finding the ratio of the means for the two sexes. Each estimate therefore needs to be multiplied by the sex-ratio at the minimum age to give the sex-ratio of animals above that age. The black symbols are calculated directly from the data, the re ones reweight it to remove the effects of a 7% *p.a.* growth rate and therefore should approximate the results for a stable population.

Figure 20 suggests that the sex-ration of animals aged over 1 is approximately 0.7-1 times the sex-ratio of one year old animals. While the visible differences in figures 16 & 17 suggest caution in believing this result, the decline in the estimated sex-ratios across figure 20 does not directly confirm this (a similar pattern would be observed even from a pair of exponential distributions with differing rates of decay).

The reweighted analysis (red symbols in figure 20) suggest that the sex ratio in a stable grey seal population is likely to be substantially (~14%) lower than in one that is growing steadily, even under the assumption that density dependence does not affect males more than females.

Pup survival estimates from Hall et al (2001).

For a male pup in average condition (0 41 kg cm-') the estimated annual survival after adjusting for tag-loss was 0.4193 (SE = 0 084); for a female pup in average condition (0 39 kg cm-') it was 0.617 (SE = 0 155).

Approximating each of these distributions by a gamma distribution with the appropriate mean and variance, then drawing 10000 bootstrap estimates from each one give an overall estimate of the ratio of male to female pup survival of 0.34 (95% CI: 0.1-0.78). The confidence interval is likely to be conservative as the two parameter estimates come from a common model. Both of them will be negatively correlated with the estimates of recapture probability and probability of emigration, which will in turn, make them positively correlated. This caution could be hoped to provide protection from any model misspecification in Hall et al, the effects of which are likely to be mitigated by the use of the ratio of the estimates rather than the separate estimates which could be expected to contain parallel biases).

In fact, directly fitting a binomial glm to the numbers of male and female resightings produced a very similar distribution (mean=0.35; 95% CI: 0.16-0.77). Because there was less recapture data, it produced a slightly less precise result (mean=0.32; 95% CI: 0.11-0.95). Combining the two types of sightings could increase the precision of the result, but would require duplicate observations to be removed. Essentially this replaces the various assumptions for the models by simpler assumptions that all the animals have equal chances of being observed.

Combining the estimated ratio of the pup survivals given in Hall *et al.* with the estimate for the ratio of mean ages of Hewer's animals (figure 20) gives an overall sex ratio of 0.28 males per female (95% CI: 0.08-0.65). Correcting for population growth, and assuming that density dependence affects both sexes equally, suggests that a stable population would have 0.23 males per female (95% CI: 0.07-0.54).

However, the sample of postweaning pups contained 96 males and 108 females. If they were selected randomly from the colony the proportion of males would be estimated at 0.471 (95% CI 0.403-0.539) giving 0.89 males per female (95% CI: 0.67-1.14). Combining this with the relative pup survivorship gives a sex-ratio of one-year olds of 0.29 (95% CI: 0.08-0.69) males per female. This comes down to 0.244 (95% CI: 0.07-0.58) when adjusted by the ratio of adult mean ages. In a stable population the equivalent figure would be 0.20 (95% CI: 0.06-0.48).

This suggests that a single multiplier would need to be centred around 1.22 and have its central 95% running from around 1.06 to 1.58. A shifted gamma, defined as 1+gamma(scale=0.1,shape=2) would seem a suitable way to approximate this (Figure 21).

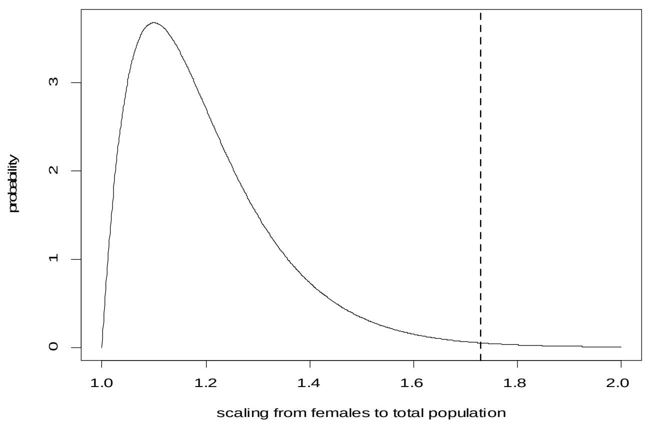


Figure 21: a possible distribution for the scaling of females to total population (broken line is value currently used in the population estimate):

Hall *et al.* (2002)
This data, and some of the difficulties in its analysis are described on page 4, above. However, the ratios of male to female recaptures and resightings can be used to refine the estimation of sex-ratio that was based on Hall *et al*. (2001). There is not enough data from either island on its own to produce an estimate with any useful precision. Combining the Isle of May resightings from Hall *et al.* (2001) with the equivalent data from the Farnes in Hall *et al.* (2002) gives an estimate that there are 0.46 males per female at age 1 (95% CI: 0.25-0.86). A gam fitted to the combined recapture data suggests a non-linear shift in sex ratio (driven by the Farnes data), leading to very wide confidence intervals at age 1 (mean =0.84; 95% CI: 0.21-3.34), and a glm fitted to the same data has similar results (mean=0.41, 95% CI: 0.17-0.97).

Hall *et al.* (2009)
In 2002 mobile phone tags were attached to 60 grey seal pups on the Isle of May. *Tags lasted 6 months due to battery life, so survival estimates were calculated for the period December to June and annual estimates were adjusted accordingly.*

- data was received from 55
- scaling up to a full year gave *estimated annual survival probability for males in average condition of 47.5% and females of 63.9% (after accounting for the effect of tag loss*. – that is a point estimate of sex ratio at age 1 of 0.74:1.
- They state*: Lower recaptures in February to April probably reflect an exploratory behavioral phase where the pups disperse to sea before establishing regular foraging patterns*

Other data

Pomeroy *et al.* (1994)
10 ground counts of animals within their Study Area on North Rona are reported (Table 5):

Table 5

Year	date	N_{males}	$N_{females}$	N_{males} /$N_{females}$
1987	11 October	26	197	0.13
	18 October	23	237	0.10
	28 October	25	122	0.20
1988	3 October	19	114	0.17
	15 October	17	167	0.10
	26 October	21	98	0.21
	3 November	14	58	0.24
1989	17 October	29	239	0.12
	23 October	21	180	0.12
	3 November	19	77	0.25

The mean sex-ratio in these data is 0.16. Hewer (1974; p134) estimates the number of males per female on breeding colonies as being in the range 0.08-0.14. However these all these estimates are for adults within the main body of breeding colonies, hey therefore exclude peripheral and non-breeding individuals. The overall effect is therefore likely to be that they underestimate the number of males in the population.

Schwartz and Stobo (2000); Manske *et al.* (2006)
These two papers used similar methods, based on branded pups that were resighted as breeding adults on Sable Island. Schwartz and Stobo estimated adult female survival at 0.92 (SE=0.014). Manske *et al*. estimated adult male survival at 0.976 **(**SE 0.003), though they suggested that this estimate may be biased upwards by its focus on animals within the core of the breeding colony. The finding that adult males survived better than adult females is difficult to reconcile with both the results of the other studies of this species and information from other mammal populations.

Conclusion:

Unless males are believed to live longer than females, the ratio of the pup survival estimates from Hall *et al*. seems sufficient to indicate that the current simple scaling of 1.73 is too high. If the analysis based on the ratio of the mean ages of the two sexes is anywhere near the truth then the correct value is likely to be much lower.

The very similar sizes of Hewer's samples of males and females is difficult to reconcile with the differential pup survivals. At the very least that reconciliation would seem to imply differential sampling of the sexes. If that had the side effect of biasing sampling towards obvious mature males and females, it could lead to the under-representation of immature animals and biases in the estimated age-structures. Detailed modelling of the age structure of the Hewer samples might reveal and remove some of the imprecision and bias associated with these simple methods, but would depend on access to and understanding of the samples' provenance.

The changes in sex-ratio as a population shifts from exponential growth to settle at the environment's carrying capacity appear much smaller than the uncertainty in these estimates. That suggests that there may only be limited direct benefit to be had from moving from rescaling to explicitly modelling male survival. However, considering the pattern within groups of animals that could be expected to have similar behaviours (eg mature males or immature individuals) might give some understanding of the biases in the sampling, as could the comparison of sub-samples collected at different times of year or in different ways.

Utilising the datasets based on samples collected during breeding season culls is likely to be more difficult, since the information they contain on age-structure and population sex-ratios is confounded with the effects of fecundity. It would therefore require a precise estimate of this quantity.

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The status of British harbour seal populations in 2011

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Summary

In August 2011, the Sea Mammal Research Unit (SMRU) surveyed the Outer Hebrides and the wider Moray Firth. Northern Ireland and the north and part of the west coast of Ireland were also surveyed.

In England, harbour seals were surveyed from fixed-wing aircraft in Lincolnshire, Norfolk, Suffolk, Essex and Kent. The Tees Seal Research Programme kindly provided information on seals in the Tees Estuary (Woods, 2011).

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 2011, the minimum number of harbour seals counted in Scotland was **21,291**and in England **4,023** making a total for Great Britain of **25,314** (Table 1). Including 948 harbour seals counted in Northern Ireland in 2011, the new UK total was **26,262**.

The number of harbour seals counted in the Outer Hebrides in 2011was **2,739**, 51.8% higher than the last complete count of **1,804** in 2008. In the Moray Firth, both breeding season and moult counts were lower in 2011 than in 2010. In the Firth of Tay, the 2011 count (77) was the lowest recoded and was 37.9% lower than in 2010 (124).

During the 2011 breeding season, SMRU conducted four aerial surveys of harbour seals breeding in the Moray Firth, continuing the time series started by the University of Aberdeen. One survey was aborted due to heavy and persistent rain. A single breeding season survey was also carried out in England, between the Humber Estuary and Goodwin Sands off Kent, in early July 2011 .

Introduction

Most surveys of harbour seals are carried out during their annual moult, in August. At this time during 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. However, during a survey, there will be a number of seals at sea and not 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 (Figure 2).

In 2011, as between 2007 and 2010, 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, which holds over 90% of the English harbour seal population, is usually surveyed twice annually during the August moult and, since 2004, Natural England have funded 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 2012, with additional funding from SNH and the Irish National Parks and Wildlife Service, surveys will cover the Orkney and the north coast of Scotland, and part of the Irish Republic.

Funding from Scottish Natural Heritage

Scottish Natural Heritage (SNH) has provided funding for harbour seals surveys in every survey year since 1996. Without this additional funding, we would not have known about the serious decline in numbers in Shetland and Orkney, as we would not have been able to carry out surveys of these island groups in either 2001 or 2006 and would not have detected the recent declines. SNH have also funded the annual surveys of Orkney since 2007.

Methods

Seals hauling out on rocky or seaweed covered shores are well camouflaged and difficult to detect. Surveys of these coastlines are 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 digital camera equipped with an image-stabilised zoom lens. Both harbour and grey seals were digitally photographed and the images used to classify group composition.

Surveys of the estuarine haul-out sites on the east coast of Britain were made using large format vertical aerial photography or hand-held oblique photography from fixed-wing aircraft. On sandbanks, where seals are relatively easily located, this survey method is highly cost-effective.

To minimise the effects of environmental variables and to maximise the counts of seals on shore, surveys are restricted to within two hours before and 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 as the thermal imager cannot 'see' through rain and because seals will increasingly abandon their haul-out sites and return into the water.

Results

1. Minimum estimate of the size of the British harbour seal population

The overall distribution of harbour seals around the British Isles from August surveys carried out between 2007 and 2011 is shown in Figure 1. For ease of viewing at this scale, counts have been aggregated into 10km squares.

Minimum population estimates for Scotland, based on August surveys carried out between 2007 and 2011, between 2000 and 2005 and in 1996 and 1997, are shown in Table 1. The Table includes numbers from both Northern Ireland and the Republic of Ireland from surveys in 2002 and 2003 respectively. For eastern England, where repeat counts were obtained (for The Wash, Donna Nook, Blakeney Point and Scroby Sands) the mean values have been used.

The most recent minimum estimate of the number of harbour seals in Scotland is **21,291**from surveys carried out between 2007 and 2011 (Table 1). This is 4.0% higher than the 2010 total (20,474) but 26.1% lower than the previous 2000 to 2005 total of 28,812 (Table 1). The most recent minimum estimate for England is **4,023**, which is 5% lower than the 2010 count and within 0.5% of the 2009 count of **4,000**. The 2011 count comprises 3,567 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 1992 count (1,267).

Including the 948 harbour seals counted in Northern Ireland in 2011, gives a UK total of **26,262.**

2. Harbour seals in Scotland: moult

In August 2011, the Outer Hebrides, the entire Moray Firth and the Firth of Tay were surveyed. The number and distribution of harbour seals counted in the Outer Hebrides during the thermal imaging surveys in August 2011 are shown in Figure 2 with the distribution of grey seals in Figure 3. 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 and was only marginally lower than the highest count of 2,820 in 1996.

The trends in counts of harbour seals in different areas (based on Seal Management Areas) of Scotland, from surveys carried out between 1988 and 2011 are shown in Figure 6 with numbers in Table 1.

Moray Firth

Aberdeen University's Lighthouse Field Station, in Cromarty, obtained detailed annual breeding and moult counts of harbour seals in the Inner Moray Firth from June, July and August between 1988 and 2005. These counts for the inner Moray Firth, from Ardersier to Loch Fleet, are shown in Figure 7a (breeding) and 7b (moult). SMRU's counts of the same area are included, along with counts from a slightly larger area, including Findhorn and the coast between Loch Fleet and Helmsdale.

SMRU's August aerial surveys of harbour seals in the Moray Firth started in August 1992. The August counts are shown in Table 2 with the trends in different parts of the Moray Firth in Figure 8. This figure represents a combination of both thermal imaging and fixed wing surveys of the area. In 2011, the Inner Moray Firth (Ardersier to Loch Fleet) count was 674, 30.0% lower than the high August 2010 count (975; Table 2, Figures 7b and 8). Following years of decline, harbour seal numbers in the Moray Firth increased in 2009 and 2010 (Figure 8; 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).

Firth of Tay

The 2011 count for the Firth of Tay (77) was 37.9% lower than the 2010 count (124). This new lowest ever count for this harbour seal SAC was only 12.0% of the mean of counts between 1990 and 2002 (641). In 2007, 147 harbour seals were counted in the Firth of Forth. Previously we suggested that these seals were from the same population.

In the summer of 2011, six dead pregnant harbour seals were found around the Eden and Tay estuaries, with corkscrew injuries. By mid-July 2012, three more adult females and one adult male were found. This level of mortality may have been a contributory factor in the recent decline and will seriously impinge on this population's ability to recover (SCOS BP_05/12) .

All licences that have been issued by Marine Scotland to shoot seals in this seal management area exclude harbour seals.

3. Harbour seals in Scotland: breeding season
Moray Firth

During the 2011 breeding season, SMRU completed four out of five aerial surveys harbour seals in the Moray Firth between mid-June and mid-July. The fourth survey was impossible due to poor weather. The mean number of adults counted during these surveys, with standard errors, is shown in Figure 7a. The mean count of harbour seal adults breeding in the Inner Moray Firth, between Ardersier and Loch Fleet, in 2011 was 681, 5.5% lower than the 2010 mean count of 721. The 2011 mean count in the Outer Moray Firth, between Findhorn and Helmsdale of 796 was 3.0% lower than the 2010 mean count of 821.

4. Harbour seal surveys in England: moult

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 4, Figure 8).

Two aerial surveys of harbour seals were carried out in Lincolnshire and Norfolk during August 2011 (Tables 1 and 4). In The Wash, the higher count in 2011 (2894) was 6% lower than the higher count in 2010 (3086) and was similar to the 2009 counts .

Overall, the combined count for the English east coast population (Donna Nook to Scroby Sands) in 2011 was 5% lower than the 2010 count but still 15% higher than in 2008. (Figure 8, Table 4). This apparent sudden change from a continual decline to a rapid recovery is as yet unexplained. 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% between 2008 and 2011.

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).

5. Harbour seals in England: breeding season

A peak of 1,106 pups and 3,283 older seals (1+ age classes) were counted in The Wash during the 2011 breeding season survey compared with 1,432pups and 3,702 older seals counted in July 2010. Pups were widely distributed, being present at all occupied sites in 2011 (SCOS BP 04/12). The 2011 pup and adult counts were 23% and 12% lower respectively than the 2010 counts, and similar to those from 2009. . The similarity of pup counts between 2006 and 2008 suggested that, like the moult counts, the production was not increasing rapidly as seen in the Wadden Sea. The average pup count in 2009 to 2011 was 25% higher than the average count form 2006 to 2008. This is consistent with the recent large increases in the moult count.

6. Proposed harbour seal surveys 2012.
Breeding season

Five breeding season fixed-wing surveys were carried out in the Moray Firth in June and July 2012.

A single survey was carried out on 2nd July 2012 between Donna Nook and Scroby Sands in Suffolk.

Moult - 2012 surveys

In Scotland, a survey of Orkney is planned for August 2011weather and equipment permitting. The remainder of the Republic of Ireland is also scheduled to be surveyed. The same methods will be used as in previous years, reviewing counts from digital still images.

In England, two fixed-wing surveys of the Lincolnshire and Norfolk coast will be carried out in early August 2011.

Acknowledgements

We are extremely grateful to all the Countryside Agencies for providing funding for carrying out surveys of seals in their 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 for northern and southern Ireland respectively.

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

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Figure. 1. The August distribution of harbour seals in Great Britain and Ireland, by 10km squares. These data are from surveys carried out between 2007 and 2011 in Great Britain and 2002-2003 in Ireland

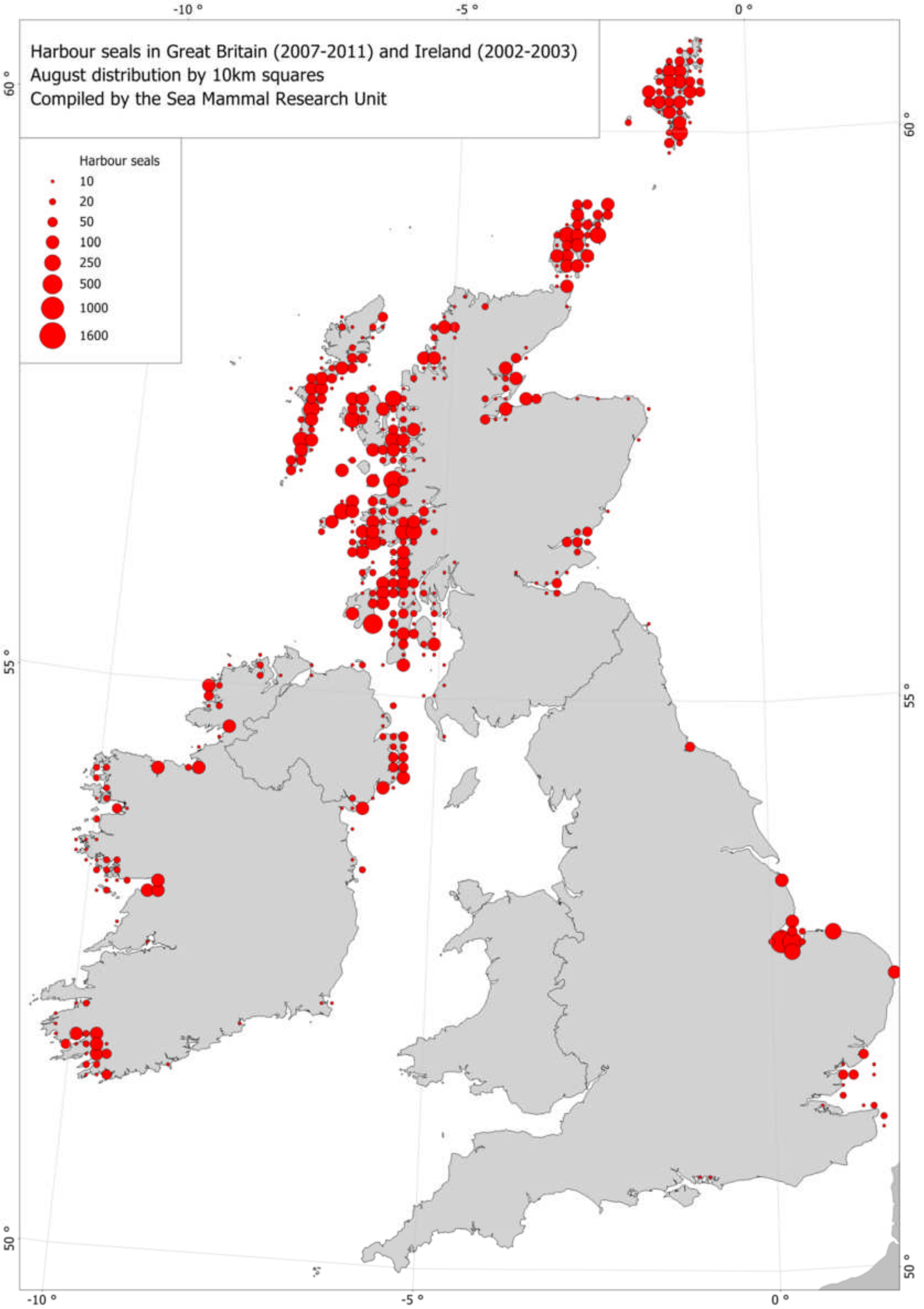


Figure 2. Harbour seals in the Outer Hebrides, surveyed in August 2011.

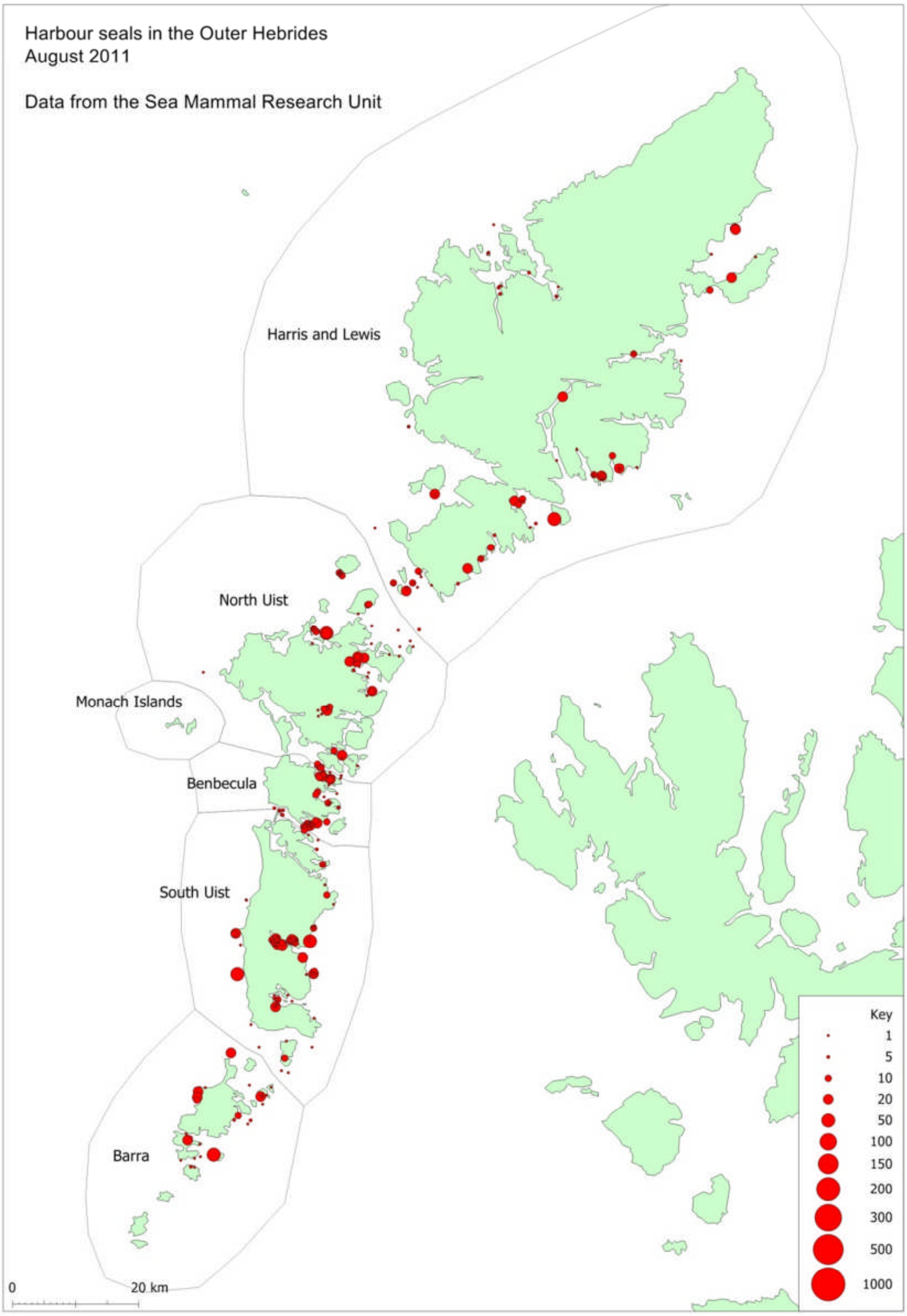


Figure 3. Grey seals in the Outer Hebrides, surveyed in August 2011.

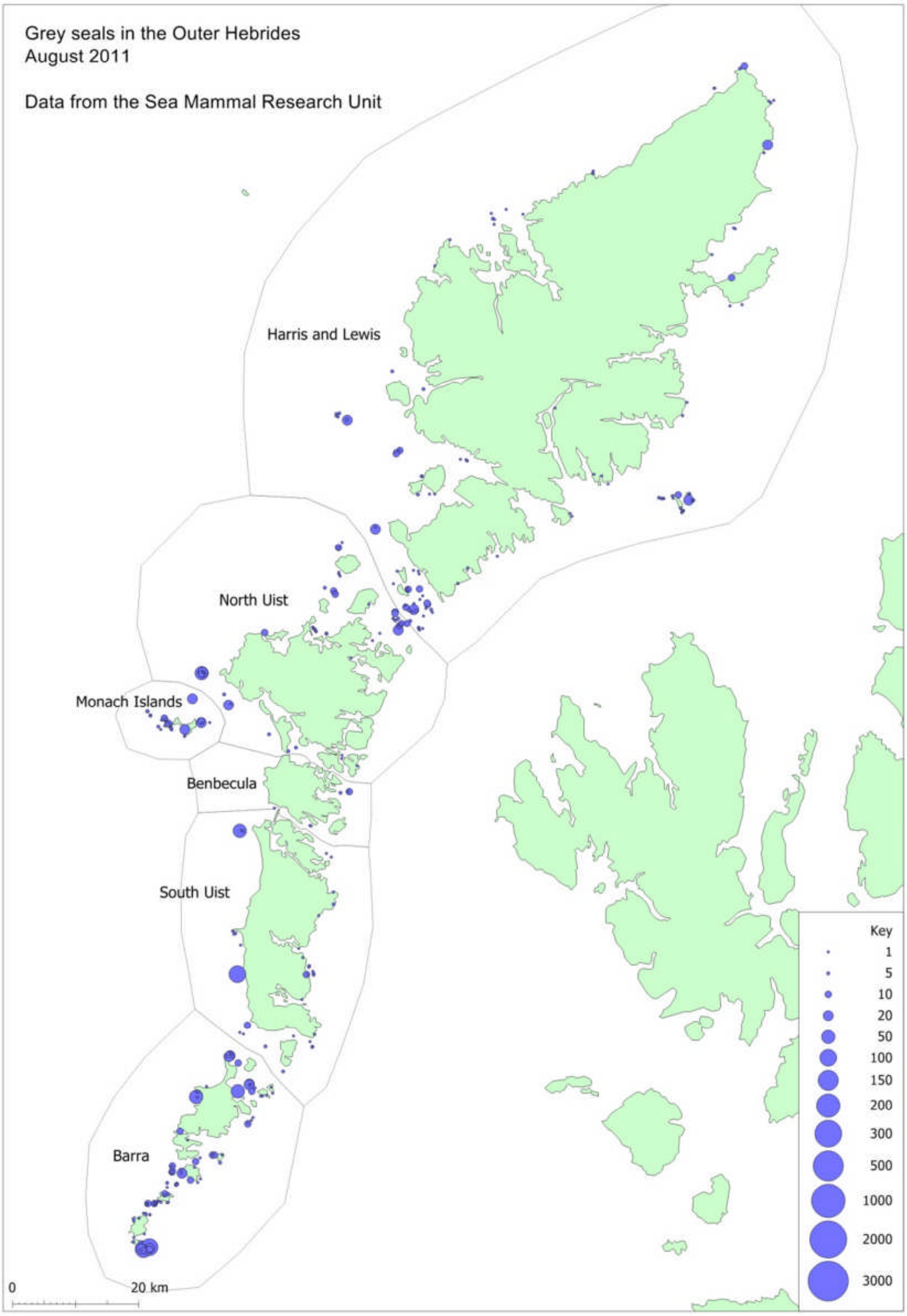


Figure 4. The number and distribution of harbour seals in Management Areas around the coast of Scotland, from surveys carried out between August 2007 and 2011. All areas were surveyed by helicopter using a thermal imaging camera.

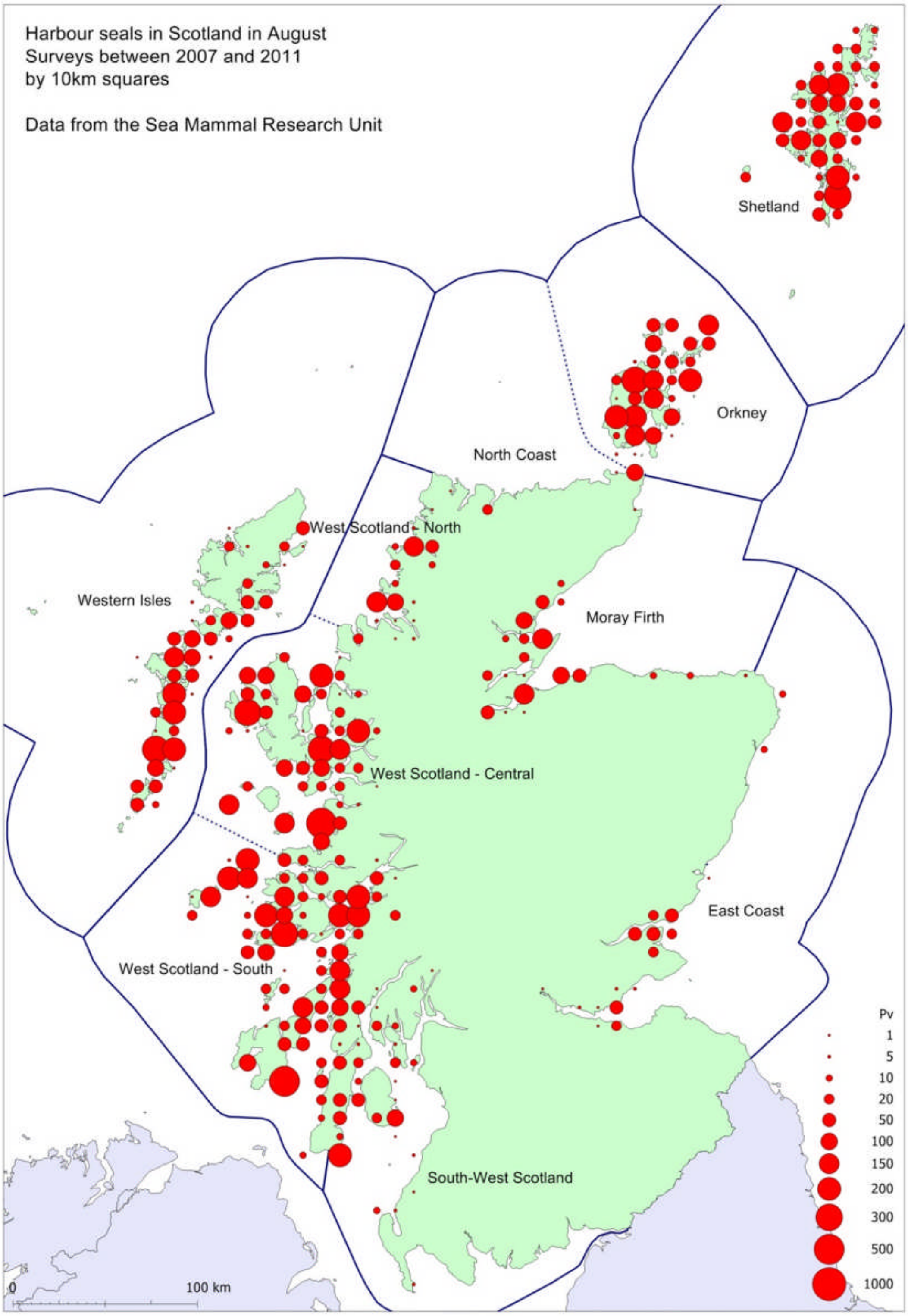


Figure 5. The number and distribution of grey seals in Management Areas around the coast of Scotland, from surveys carried out between August 2007 and 2011. All areas were surveyed by helicopter using a thermal imaging camera.

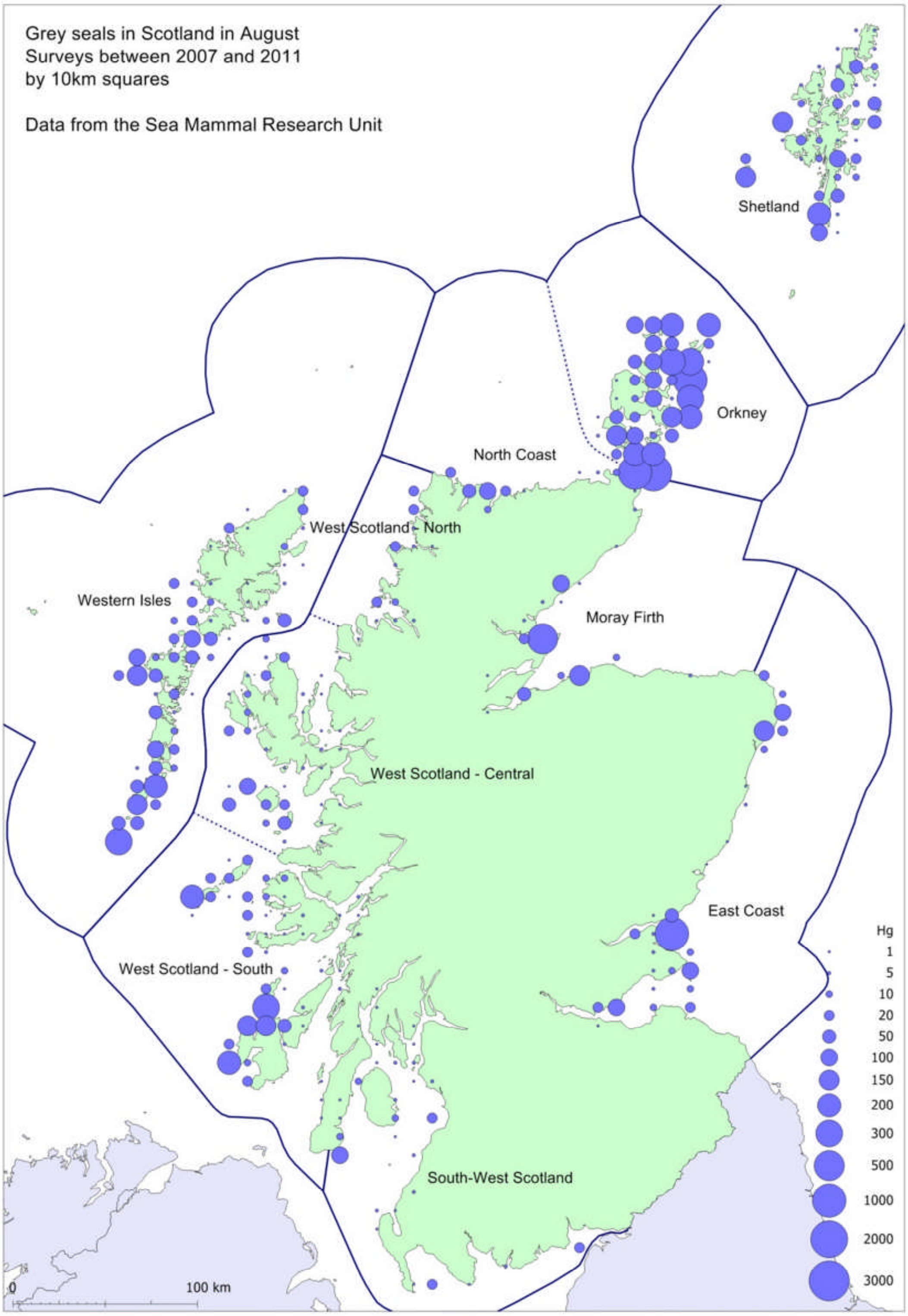


Figure 6. Trends in counts of harbour seals in Management Areas around Scotland. Data from the Sea Mammal Research Unit. Solid symbols show where data were from one or two years; open symbols show where data were collected over more than two years.

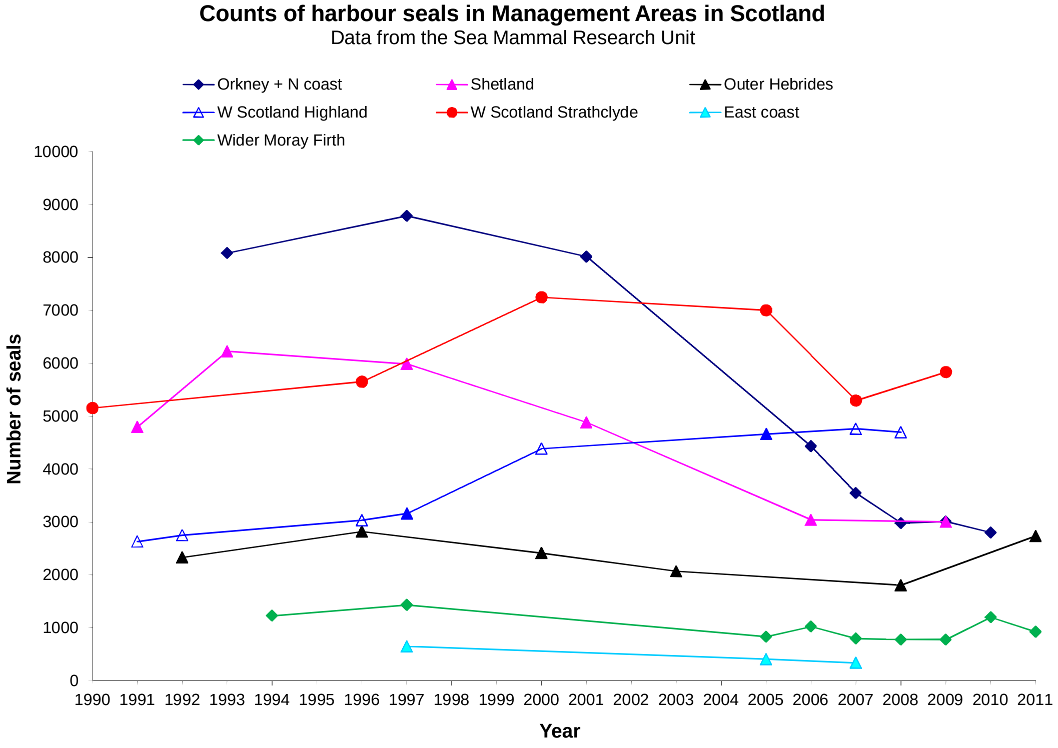
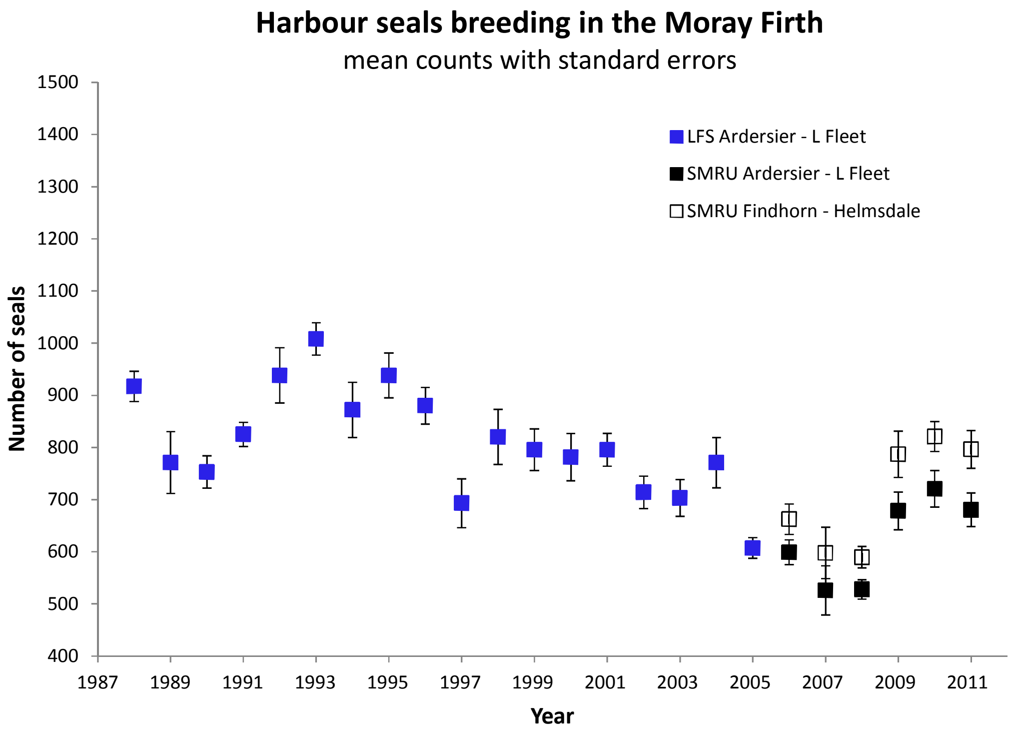


Figure 7. Trends in harbour seal numbers in the Moray Firth since 1988. Seals were counted during their breeding season (a) and during their moult (b) by the University of Aberdeen's Lighthouse Field Station (LFS) and more recently by SMRU. Comparable areas are the Inner Firths plus Loch Fleet. SMRU surveys include additional Moray Firth colonies at Findhorn and along the coast between Loch Fleet and Helmsdale.

a)



b)

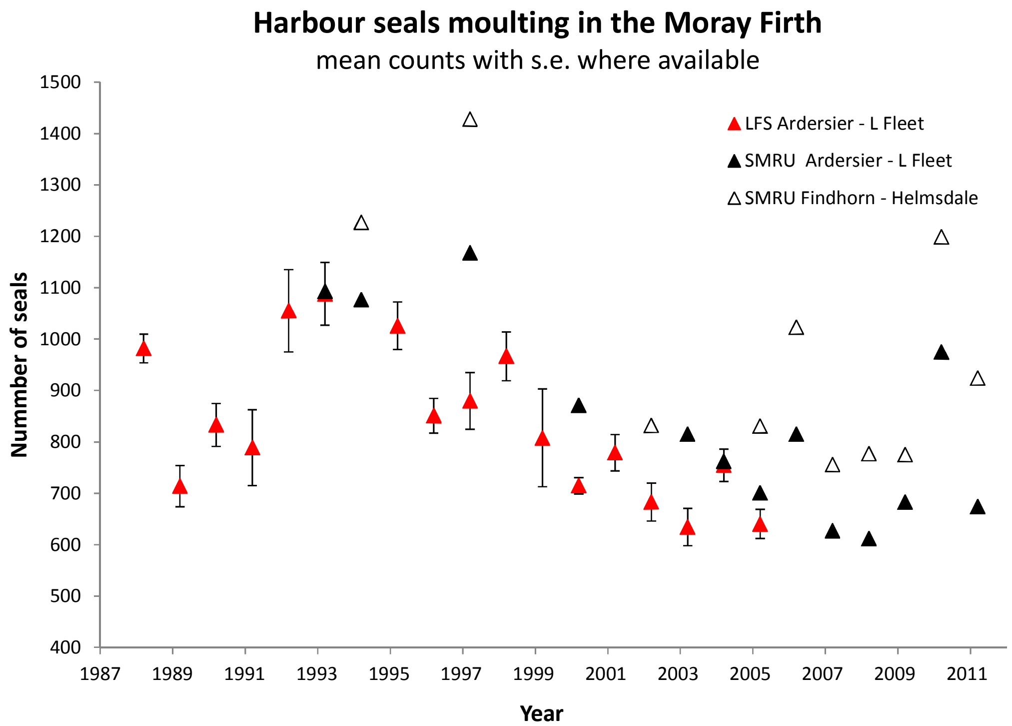


Figure 8. The number of harbour seals counted in areas within the Moray Firth between 1992 and 2011 by the Sea Mammal Research Unit.

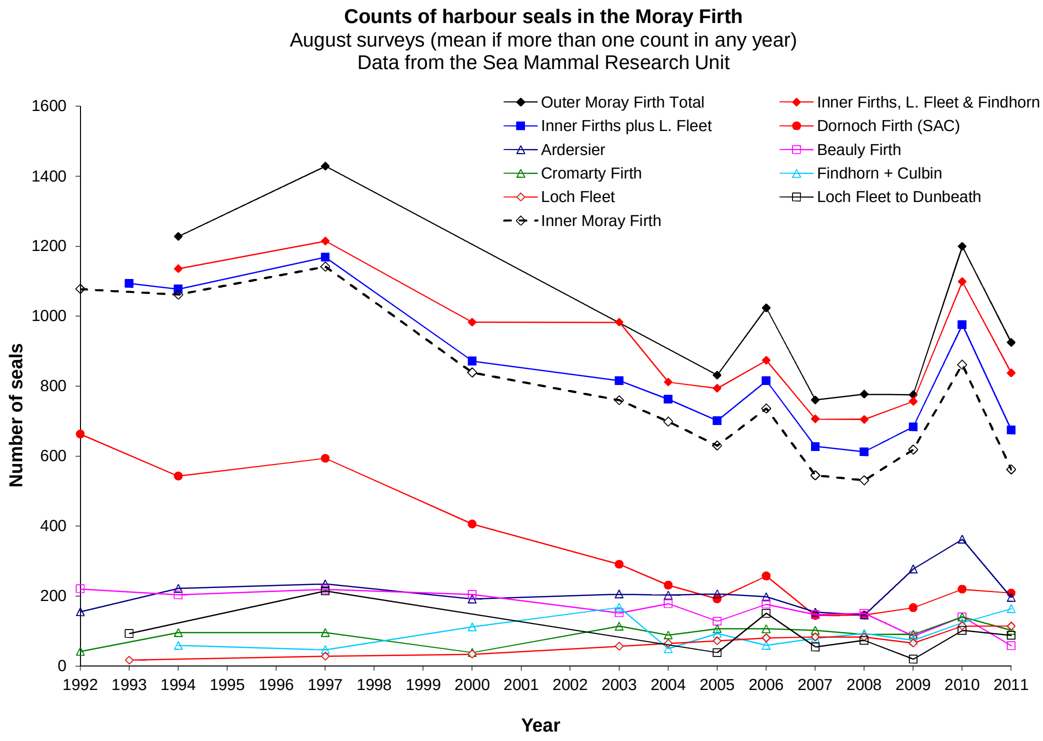


Figure 9. The number of harbour seals counted in the Firth of Tay between 1990 and 2011 by the Sea Mammal Research Unit.

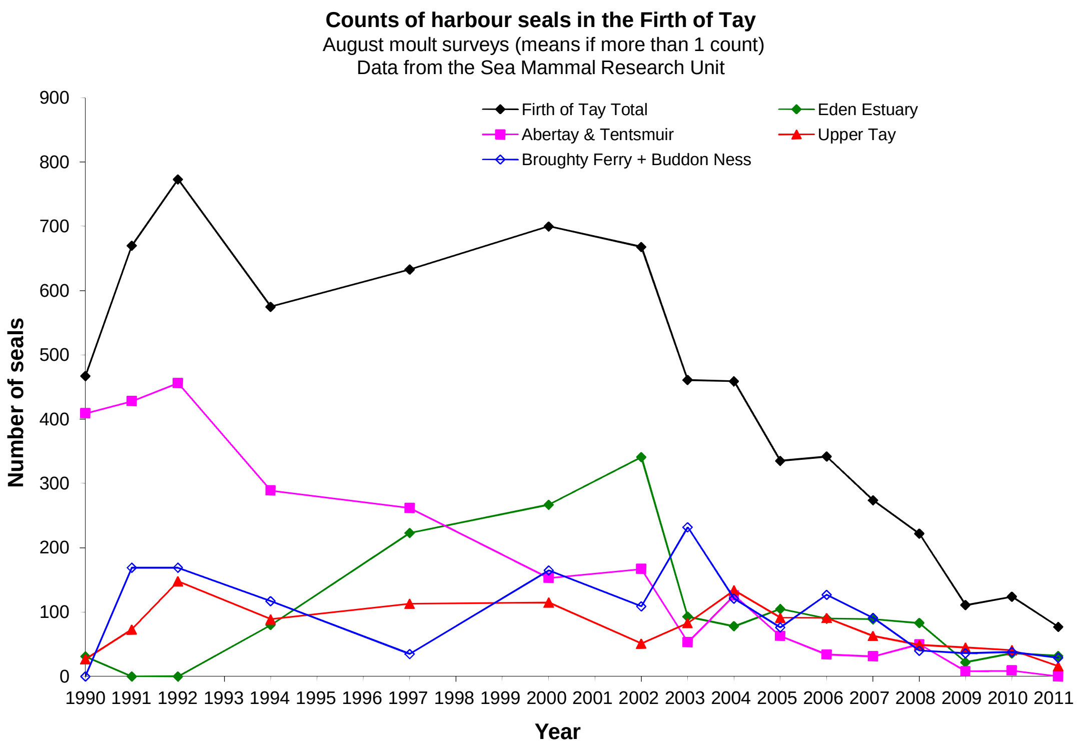


Figure 10. Counts of harbour seals in The Wash in August, 1967 - 2011. These data are an index of the population size through time. Fitted lines are exponential growth curves (growth rates given in text) with a 2nd order polynomial for post-2002 counts for illustration.

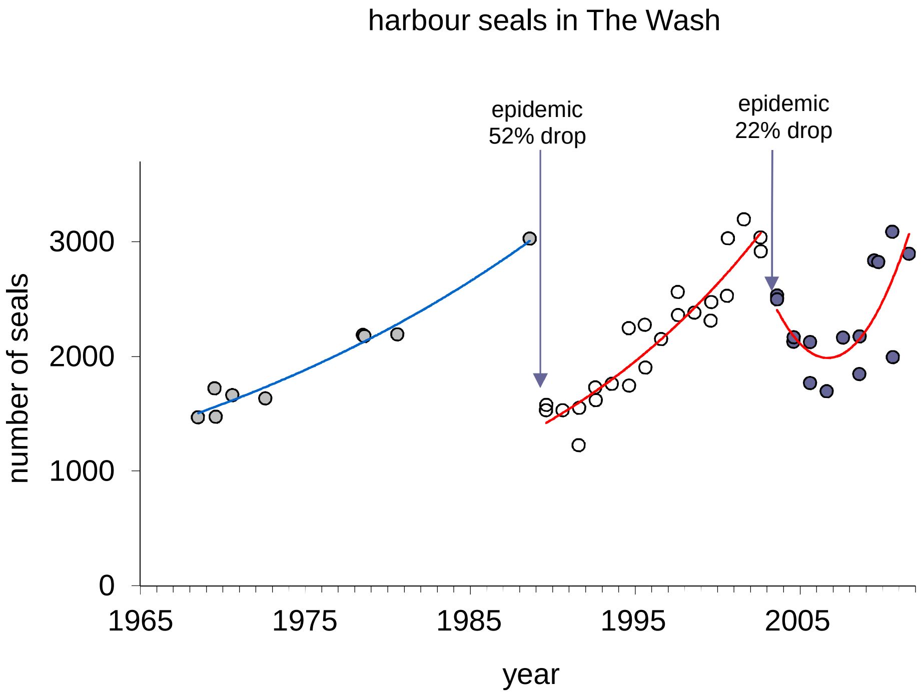


Table 1. Minimum estimates of the UK harbour seal population in Management Areas from the most recent and from two previous surveys. . These are the numbers of seals counted in aerial surveys with the survey year below the number of seals counted.

Harbour seal count area or Management Area	Current count (2007-2011)	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
Highland North coast	**112** 2008	**174** 2005	**265** 1997
Outer Hebrides	**2,739** 2011	**2,067** 2003	**2,820** 1996
West Scotland, Highland (Cape Wrath to Ardnamurchan Point)	**4,696** 2007, 2008	**4,665** 2005	**3,160** 1996, 1997
West Scotland, Strathclyde (Ardnamurchan Point to Mull of Kintyre)	**5,914** 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 at Carlisle)	**23** 2007	**42** 2005	**6** 1996
East Scotland, Firth of Forth (Border to Fife Ness)	**148** 2007	**280** 2005	**116** 1997
East Scotland, east coast Fife Ness to Fraserburgh	**167** 2007, 2011	**406** 2005	**648** 1997
East Scotland, Moray Firth (widest) Fraserburgh to Duncansby Head	**954** 2007, 2011	**959** 2005	**1429** 1997
TOTAL SCOTLAND	**21,291**	**28,812**	**29,532**
	(2011)	(2005)	(1997)
Blakeney Point	**349**	**709**	**311**
The Wash	**2,894**	**1,946**	**2,461**
Donna Nook	**205**	**421**	**251**
Scroby Sands	**119**	**57** 2004	**65**
Other east coast sites	**436**	**153** 1994-2003	**137** 1994 –1997
South and west England (estimated)	**20**	**20**	**15**
TOTAL ENGLAND	**4,023**	**3,306**	**3,240**
TOTAL BRITAIN	**25,314**	**32,118**	**32,772**
TOTAL NORTHERN IRELAND	**948** 2011	**1,248** 2002	
TOTAL BRITAIN & N. IRELAND	**26,262**	**33,366**	
TOTAL REPUBLIC OF IRELAND	**2,905** 2003	**2,905** 2003	
TOTAL GREAT BRITAIN&IRELAND	**29,167**	**36,271**	

Table 2. Numbers of harbour seals in the Moray Firth during August (SMRU surveys). See Figure 8. Fw = fixed-wing survey; ti = helicopter thermal image survey. Where asterics replace dates, values are means of multiple surveys.

Location	07 Aug 1992	30 July 1993	13 Aug 1994	15 Aug 1997	11 Aug 2000	11 Aug 2002	7 Aug 2003	* Aug 2004	* Aug 2005	* Aug 2006	* Aug 2007	* Aug 2008	6 Aug 2009	18 Aug 2010	9 Aug 2011
Survey type	fw	ti	fw	ti	fw	ti	fw	fw	fw, ti	fw, ti	fw, ti	fw, ti	fw	fw	ti
Ardersier	154	-	221	234	191	110	205	202	206	197	154	145	277	362	195
Beauly Firth	220	-	203	219	204	66	151	178	127	176	146	150	85	140	57
Cromarty Firth	41	-	95	95	38	42	113	88	106	106	102	90	90	140	101
Dornoch Firth (SAC)	662	-	542	593	405	220	290	231	191	257	144	145	166	219	208
Inner Moray Firth Total	**1077**	**-**	**1061**	**1141**	**838**	**438**	**759**	**698**	**630**	**736**	**545**	**530**	**618**	**861**	**561**
Findhorn	-	-	*58*	*46*	*111*	*144*	*167*	*49*	*93*	*58*	*79*	*92*	*73*	*123*	*163*
Loch Fleet	-	*16*		*27*	*33*	*62*	*56*	*64*	*71*	*80*	*83*	*82*	*65*	*114*	*113*
Loch Fleet to Dunbeath	-	*92*		*214*		*188*	-	-	*38*	*150*	*54*	*73*	*19*	*101*	*87*
Outer Moray Firth Total				**1428**		**832**			**831**	**1023**	**760**	**777**	**775**	**1199**	**924**

Table 3. Numbers of harbour seals in the Firth of Tay during August. See Figure 9. Fw = fixed-wing survey; ti = helicopter thermal image survey. Where asterics replace dates, values are means of multiple surveys.

Location	13 Aug 1990	11 Aug 1991	07 Aug 1992	13 Aug 1994	13 Aug 1997	12 Aug 2000	11 Aug 2002	7 Aug 2003[1]	10 Aug 2004	* Aug 2005	14 Aug 2006	* Aug 2007	29 Aug 2008	7 Aug 2009	16 Aug 2010	17 Aug 2011
Survey type	fw	fw	fw	fw	ti	fw	fw	fw	fw	fw, ti	fw	fw, ti	fw	fw	fw	fw
Eden Estuary	31	0	0	80	223	267	341	93	78	105	90	89	83	22	36	32
Abertay & Tentsmuir	409	428	456	289	262	153	167	53	126	63	34	31	50	8	9	0
Upper Tay	27	73	148	89	113	115	51	83	134	91	91	63	49	45	41	16
Broughty Ferry & Buddon Ness	0	169	169	117	35	165	(109)	232	121	76	127	91	40	36	38	29
Firth of Tay Total (SAC)	**-**	**670**	**773**	**575**	**633**	**700**	**(668)**	**461***	**459**	**335**	**342**	**274**	**222**	**111**	**124**	**77**

[1]In August 2003 low cloud prevented the use of vertical photography; counts were from photographs taken obliquely and from direct counts of small groups of seals.

Table 4. 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 during the August moult.

Date	**13/8**	**8/8** **12/8**	**11/8**	**2/8** **11/8**	**1/8** **16/8**	**8/8**	**6/8** **12/8**	**5/8** **15/8**	**2/8**	**2/8** **8/8**	**7/8** **14/8**	**3/8** **13/8**	**4/8** **12/8**	**4/8**	**11/8** **12/8**	**9/8** **10/8**	**6/8** **14/8**	**09/8**	**15/8**	**3/8**	**8/8** **16/8**	**9/8** **14/8**	**8/8** **14/8**	
Year	**1988**	**1989**	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**
Blakeney Point	701	- 307	73	- -	- 217	267	- 196	438 392	372	250 371	535 738	715 602	895 dstrb	772	346 631	399	577 715	741 677	719	550	620 541	372	391	349
The Wash (SAC)	3087	1531 1580	1532	1226 1551	1724 1618	1759	2277 1745	2266 1902	2151	2561 2360	2367[1] 2381	2320 2474	2528 3029	3194	3037 2916	2529 2497	2126 2167	1768 2124	1695	2162	1846 2174	2835 2823	3086 1992[4]	2894
Donna Nook	173	- 126	57	- -	18 -	88	60 146	115 36	162	240 262	294 201	321 286	435 345	233	341 -	231	242 346	372 470	299	214	132 250	170 363	164 188	205
Scroby Sands	-	- -	-	- -	- -	-	61 -	- 49	51	58 72	52 -	69 74	84 9	75			49 64		71		60 101	100 230	219 183	119
The Tees	-	- -	-	- -	- -	-	- 35	- -	-	- -	- -	- -	- -	-	-		- -	-	-		41[3]	49[3]	53[3]	57[3]
Holy Is, N'bld	-	- -	-	- -	- -	-	13	- -	-	12[2]	- -	- -	10	-	-		- -	17[2]	-	7				
Essex, Suff & Kent	-	- -	-	- -	- -	-	- -	90 -	-	- -	- -	- -	- -	-	- 72	190	- -	101	-		299		379	

[1] One area used by harbour seals was missed on this flight (100 – 150 seals); this data point has been excluded from analyses. Totals are means when more than one survey of any area in any year.
[2]Holy Island surveyed by helicopter using a thermal imaging camera
[3]Tees data kindly provided by Robert Woods, INCA (Woods 2008, 2009, 2010, 2011)
[4]Possible disturbance due to cockle fishery.

Mike. Lonergan & Dave. Thompson

Harbour seal (*Phoca vitulina*) abundance within the Firth of Tay and Eden Estuary Special Area of Conservation: recent trends and extrapolation to extinction

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Summary
Simple models are used to examine the recent declines in the numbers of harbour seals counted in the Firth of Tay and Eden Estuary Special Area of Conservation. These suggest that the continuation of current trends would result in the species effectively disappearing from this area within the next 20 years. While the cause of the decline is unknown, it must be reducing adult survival. Recovery of the population to the abundance when the SAC was designated is likely to take at least 40 years, even if its cause is immediately identified and rectified. Partial removal of the cause will have limited benefits. There are unlikely to be any long-term benefits from introducing or reintroducing additional individuals while the problem persists.

1. Introduction

The Firth of Tay and Eden Estuary Special Area of Conservation was designated in 2005. The common, or harbour, seal (*Phoca vitulina*) was a qualifying species that was stated to be a primary reason for the designation of the site. No other Annex II qualifying species were mentioned. The other qualifying features of the site were habitats: estuaries, sandbanks, mudflats and sandflats (http://jncc.defra.gov.uk/ protectedsites/sacselection/sac.asp?EUcode=UK0030311).

The state and importance of the seal population was then described as:

> *The intertidal sandflats of Abertay sands, the banks west of the Tay Bridge, Broughty Ferry, Buddon and Eden mouth consistently support approximately 600 common seals, about 2% of the UK and 1% of the EU populations of this species. Large colonies like these are important in maintaining the overall population size and are significant as sources of emigration to smaller or newly established groups.*

More, recently the situation has been described as:

> *In the Firth of Tay only 77 harbour seals were counted in August 2011 compared with 124 in August 2010, a decline of 37.9%. This is the lowest count for the Firth of Tay and represents only 11.5% of the mean count of 670 between 1991 and 2002.* (Duck & Morris, 2012)

This document uses data on the numbers of harbour and grey seals hauling out in the SAC, along with information from other areas and about carcasses found on beaches, to investigate the population's trajectory. In particular it attempts to estimate how long the population is likely to take to recover once the cause of the decline is removed. Recovery is defined as a local abundance such that 600 animals could be expected to be seen hauling out during an aerial survey carried out in August.

The remainder of the document is in four parts: a section describing relevant data; one listing possible proximate causes of the decline, and what can be said about their implications and likelihoods; projections of future population trajectories under plausible scenarios and assumptions; and a brief section drawing some conclusions.

Note: all the analysis is on numbers of hauled out seals. These can be converted into rough population estimates by multiplying the counts of harbour seals by 1.4 (Lonergan *et al*., in press) and those of grey seals by 3 (Lonergan *et al*., 2011).

2. What has happened

2.1. Harbour seal population trajectories in other regions

Substantial declines have been reported in all harbour seal populations in Eastern Scotland, including Orkney and Shetland (Lonergan *et al.*, 2007, in press). The population in the Moray Firth may now be stabilising after a period of decline (Duck & Morris, 2011), and abundance on the west coast of Scotland appears stable (Lonergan *et al.*, 2007). The East Anglian population has shown few signs of recovering from the 2002 epidemic of phocine distemper (Thompson *et al.*, 2005; Lonergan *et al.*, 2007), though the nearby population in the Wadden Sea is increasing rapidly (TSEG, 2011). Declines have also been reported for some populations in Eastern Canada and Alaska (IUCN, 2008). However, globally the species remains relatively abundant and unthreatened (IUCN, 2008).

2.2. Tay harbour seal population trajectory

The decline in the counts of harbour seals is visually very striking (Figure 1). To investigate this pattern, a generalised additive model (gam) (Wood, 2006), with quasipoisson errors and a log link function, was fitted to the data. As the later part of the trajectory appeared to resemble an exponential decay, a similar generalised linear model (glm) was also fitted, with different exponential rates of population growth up to 2000 and from 2001 onwards. The transition point was chosen visually, but its suitability was checked by fitting models where it was one or two years earlier or later. Their residuals showed greater overdispersion, and equivalent models with Poisson errors had higher AIC, supporting the choice of this transition date.

The results of the gam and the glm with a sudden change in trajectory after 2000 were similar (Figure 1), especially for recent years. While the truth is probably somewhere between these extremes, a model where two exponential trajectories were fitted along with a shrinkage spline allowed the two representations to compete and produced results indistinguishable from the glm. A similar model containing two smooth functions and two exponential trajectories, all meeting between 2000 and 2001, produced identical results. These combined models therefore support a relatively sudden transition between two periods with different, but stable, rates of exponential population growth.

The growth rate between 1970 and 2000 was estimated at 4.5% *p.a.* (95% Confidence Interval 3.3-5.7). This lies within the range of values that have been observed in other harbour seal populations (Thompson *et al.*, 2005; Lonergan *et al.*, 2007). However, the different methodology used for the early surveys may limit their comparability with the later ones, and the reliance that can be put on this estimate.

The glm estimated the annual rate of decline since 2000 at 18% (95% CI: 14.9-21.2). That is significantly faster than the estimated rate of decline in Orkney (13% *p.a.*; 95% CI 10.8-14.8) (Lonergan *et al*., in press). Detailed examination of the modelled trajectories shows that the three most recent counts, and the associated gam predictions, lie below the trajectory estimated by the glm (Figure 1), suggesting that the decline of this population is unlikely to be slowing.

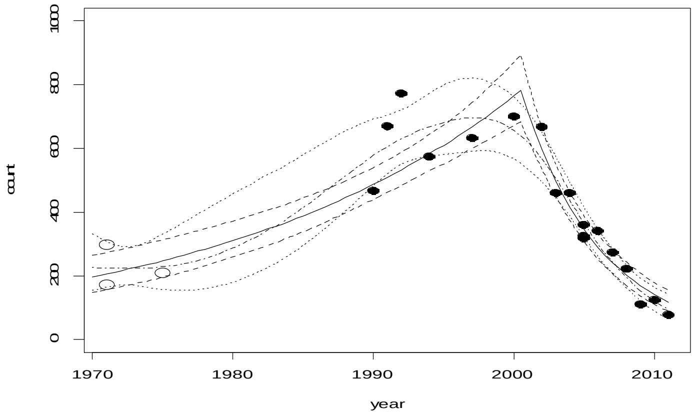


Figure 1: Numbers of harbour seals counted in aerial surveys of the Firth of Tay and Eden Estuary SAC. The surveys were carried out in August. The hollow symbols indicate surveys that used a different methodology from the rest, and therefore may not be truly comparable. The solid line is an estimated trajectory from a glm where the rate of exponential population growth changed after 2000. The broken lines around it show the associated 95% confidence intervals. The curves are the results of a gam, and assume that changes in the population growth rate changed smoothly over the period.

2.3. Trajectories of neighbouring (small) harbour seal populations

There are groups of harbour seals in the Firth of Forth and along the east coast of Angus and Grampian (between Montrose and Fraserburgh). Until recently, far fewer animals were counted in those areas than in the SAC. That difference is not so clearcut now.

There are four counts from the Forth (116 in 1997; 280 in 2005; 148 in 2007; and 147 in 2011). It is difficult to estimate trends from so few datapoints. If it is assumed that the uncertainty in these counts is similar to those from the SAC, then they can be modelled using a quasipoisson error distribution with the same overdispersion as was estimated from the Tay data (scale=13.3). Fitting a gam shows no evidence of changes in abundance over the period. A glm fitted to the data from after 2000, when the Tay counts were declining, suggests the population was probably declining (p=0.11; non-significant result), but the annual rate of change was in the range -0.24 - +0.03. The uncertainty associated with small samples means that somewhere around 45 more surveys of the Firth of Forth might be required to match the precision of the current estimate of the trend in the Tay.

The highest count for the coast from Montrose to Fraserburgh was 51 harbour seals (in 2007), so very little can be said about that trajectory beyond noting that the counts in the Tay seem likely to reach similar levels within the next few years.

Over the last ten years, 36 harbour seals have been fitted with telemetry tags in and around the SAC. Inspection of their GPS tracks showed two of them to have hauled out at or beyond Montrose to the north, and another two to have hauled out within the Firth of Forth to the south. Other individuals swam beyond these places without coming ashore there. It therefore seems unlikely that the abundance trajectories in the three areas will be wholly independent.

2.4. Harbour seal pup counts in the SAC

A total of 12 harbour seal pups were observed during onshore visual searches of the SAC in 2010, and 6 in 2011 (R. Milne, *pers. com.*). In those years 124 and 77 animals were observed during the moult aerial surveys (Duck & Morris, 2012), meaning there was 1 pup observed for every 10 animals counted in 2010. In 2011 the ratio was 1:13.

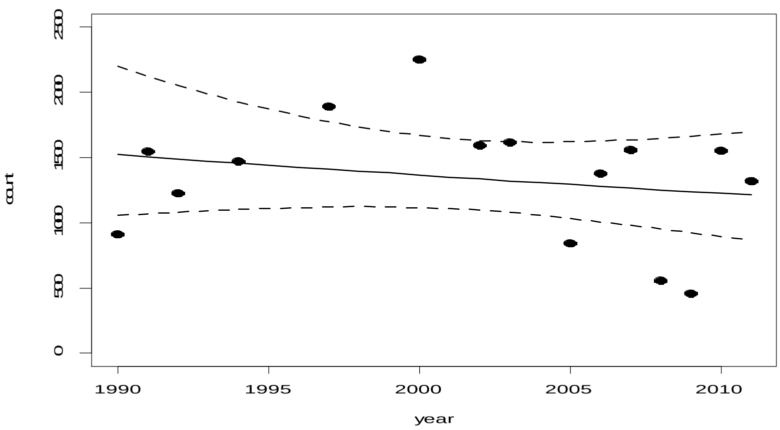
For the Wash, the ratio of peak pup numbers, observed during aerial surveys carried out in the breeding season, to mean total moult counts of animals was much higher. For each of the years 2004-2010, this was calculated to lie in the range 1:1.6 to 1:3.5 (SMRU unpublished data). In 2001, before the second phocine distemper epidemic, the ratio was estimated to be 1:5.8 (SMRU unpublished data), and a similar value has been reported from the Wadden Sea (TSEG, 2011).

The different methodologies used to find pups, and small number of estimates available, make direct comparisons difficult, but explaining away the discrepancies would seem to require the searches of the Tay to have missed most of the pups that were present. Otherwise, the low proportion of pups implies either a lower fecundity among adult females or a smaller proportion of the population to be adult females.

2.5. Tay grey seal population trajectory

Fitting a gam to the counts of grey seals showed that there has probably been a slow (~1% *p.a.*) decline in their numbers over the period since 1990. While this change is not statistically significant (95% CI: -3.9 – 1.7), it clearly shows that, at least in August, there has not been a substantial increase in grey seal numbers in the SAC. Grey seal pup production has been increasing at around 7% *p.a.* in the British North Sea breeding colonies; though production at the Isle of May, the nearest breeding colony to the SAC, has been fairly stable (Duck & Morris, 2011). The stability in the number of grey seals in the area implies that any competitive pressure they apply to the harbour seals is unlikely to have increased, unless there is a carrying capacity for pinnipeds in the area that has steadily reduced over this period.

Figure 2: Numbers of grey seals counted in aerial surveys of the Firth of Tay and Eden Estuary SAC. The surveys were carried out in August. The solid line is an estimated trajectory from a gam, and shows a steady exponential decline. The broken lines around the trajectory show the associated 95% confidence intervals.



2.6. Corkscrew mortalities

Harbour seal carcasses with distinctive spiral injuries have been found in various locations around the UK. The cause of these injuries is unknown, though the most obvious explanation is that they are caused by animals being drawn through ducted propellers on manoeuvring ships (Thompson *et al.*, 2010). A total of 25 such carcasses have been recovered near the SAC over the last five years (Table 1). This statistic seems likely to underestimate the total number of animals that are killed in this way because the data describe only animals that wash ashore and are reported, to either SMRU or the Scottish Marine Animal Strandings Scheme. Carcasses of animals that are struck far from the shore may be underrepresented in this dataset. The relative buoyancy of animals is also likely to affect the chance of their carcasses being recovered, and variation in this may make the sample unrepresentative.

If it is assumed that there are no biases, fitting binomial glm to these data suggests 13% (95% CI: 4-34) of the animals killed in this way are male, and that there is little (ΔAIC =1) reason to believe this has changed over the study period. It would be difficult to test whether the carcasses matched the sex-ratio of the surviving population, or populations under more normal conditions, because very little is known about that (Appendix 1). Treating the sex-ratio of the carcasses as an estimate of the sex-ratio of the wider population would also require further strong assumptions about the lack of selectivity of the additional mortality.

Table 1: Spiral cut harbour seals recorded in vicinity of Firth of Tay and St Andrews Bay.

	adult ♂	adult ♀	adult ?	Juv. ♂	Juv. ♀
2008*		2			
2009*		2		1	1
2010		8			
2011	1	5	2		
2012 (to 14/8/12)	2	4			

* 2008 and 2009 likely under-reporting of strandings

3. Possible proximate causes

There is one behavioural change, and another four changes in the population's demographics, with the potential to produce the observed changes:

3.1. Change in haulout behaviour

Counts of hauled out animals would fall if the proportion of time animals spent out of the water during the survey declined. However, a recent study in Orkney, where the harbour seal population is also declining rapidly, showed similar haulout behaviour to that previously reported elsewhere (Lonergan *et al*., in press). To explain the reductions reported in the Tay an 88% reduction in time spent hauled out around daytime low tides would be required.

3.2. Reduction in survival

If all pups die, populations decline at a rate determined by mortality rates among adults. The annual survival rate of male harbour seals has been estimated at 0.91, with female survival being slightly higher (Harkonen and Heidejorgensen 1990). This population is therefore declining too fast for even a total failure in recruitment to provide a complete explanation, though it could be a contributory factor. If adult female survival is assumed to have been 0.92 before the decline, then a total failure of recruitment would need to have been accompanied by a reduction in adult survival of at least 10% to produce the changes that have been observed.

The decline could simply be explained by overall survival having been reduced. Lower adult survival would increase the proportion of juveniles in the population, and result in the ratio of pup numbers to total abundance falling and an accelerating decline in abundance. A gradual lowering of the proportion of the population that is female, perhaps by additional mortality disproportionately affecting females, would have similar effects. However, while the counts and gam trajectory falling below that from the glm in recent years (Figure 1) hint at this, they provide very limited evidence to support such a conclusion. The female-bias in the recovered corkscrew carcasses is difficult to interpret, but the low numbers of pups is consistent with changes in the population structure.

3.3. Reduction in fecundity

The same argument that applies to pup survival also means lowered fecundity cannot entirely explain the decline. An additional issue is the observations of pups in 2010 and 2011 mean that, while fecundity could have been substantially reduced, it was not zero. An increase in the age of first reproduction would be equivalent to a reduction in fecundity.

3.4. Increase in emigration

Emigration is only distinct from mortality if the animals arrive somewhere else. The Moray Firth contains the only nearby harbour seal population large enough that an increase in immigration of tens of animals per year might pass unnoticed (Duck & Morris, 2012).

3.5. Decrease in immigration

There is no evidence that the Tay population has recently been receiving large numbers of immigrants, but if it had, the ending of such a transfer could cause a decline. The Moray Firth population is again the least unlikely source of animals for such a redistribution.

4. Scenarios

Attempts to predict the future trajectory of this population depend on assumptions about what has been happening and will happen in the future. This section attempts to project under some possible scenarios.

4.1. Everything continues as it has been

Projecting a 4.5% *p.a.* decline forwards will inevitably lead to population extinction. Even ignoring stochastic effects, this can be expected to occur before 2040 (Figure 3). In practice, random variations in the sex-ratio of births and timings of deaths are likely to make this occur much sooner.

A simple stochastic model of the female component of the Tay & Eden harbour seal population assuming 92% annual survival of non-pups, 40% survival of pups, 90% of females older than 3 y.o. pup each year and that half of pups are female, produces a population growth rate of 5% *p.a.*. Introducing an additional 25% mortality, affecting adults and non-pup juveniles, changes this to an 18% *p.a.* decline. Treating each birth and each individual's annual mortality risk as an independent draw from binomial distributions, and starting with a population of 50 non-pup females, suggests extinction is likely to occur after 22 years (95% confidence interval, from 1000 replicates: 13-38). Figure 4 shows the trajectories of 100 replicate simulated populations. This starting population size was chosen on the assumption that more than half of the 77 animals counted in 2011 were female, but some of those were pups. It may be slightly low to account for the proportion of animals missed because they were in the water, but the model neglects the possibility that extinction occurs as a result of all males dieing or that individual deaths are not independent. Stochasticity is only important for small populations, so the current fast rate of decline means that an 18% error in initial abundance would only be expected to move the extinction date one year.

Figure 3: Projecting the glm model of the harbour seal population forward. The broken lines are 95% confidence intervals around the best estimate.

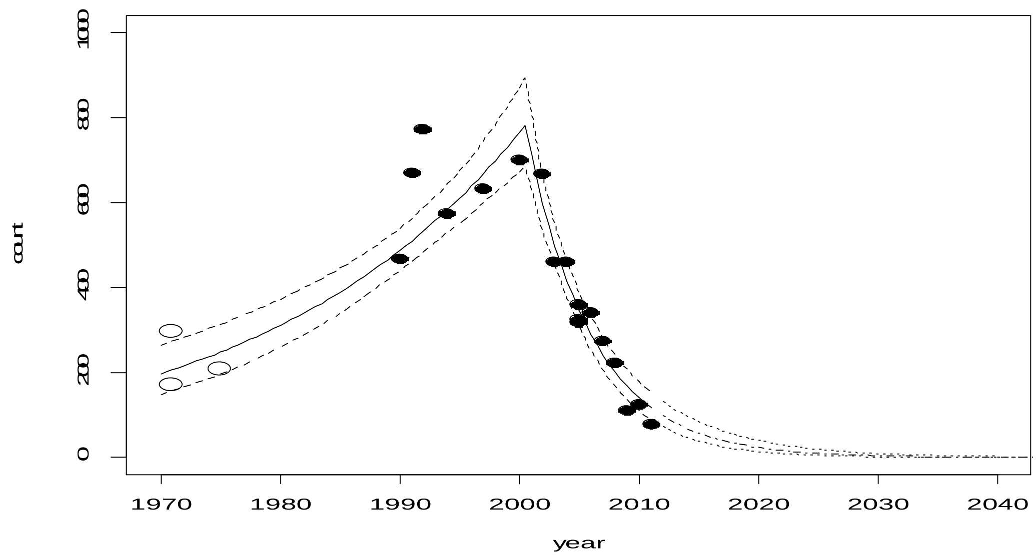
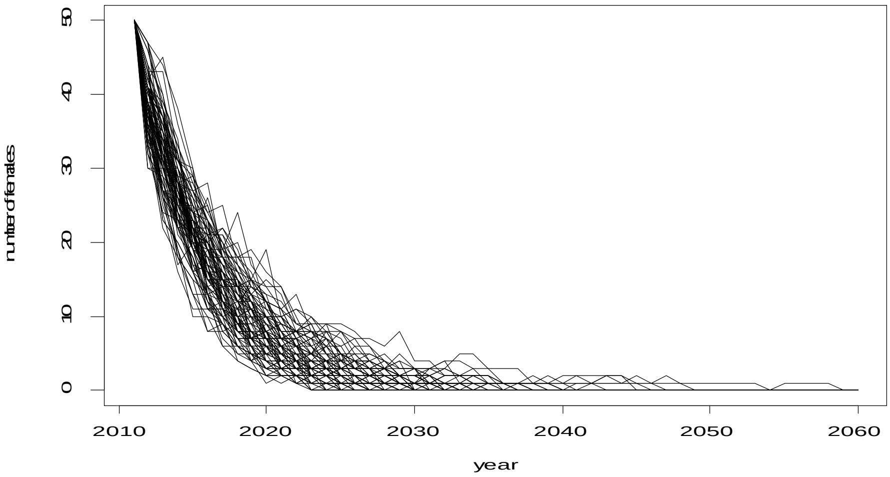


Figure 4: Simulated trajectories for the decline of the Tay harbour seal population. Each line shows the numbers of females aged at least 1. Populations that appear to recover from zero abundance are those that were reduced to contain only juveniles. By neglecting the possibility of extinction through total loss of males, this model is likely to overstate the length of time this population will survive.



4.2. The cause of the problem goes away and things return to "normal"

The glm model suggests that the 2011 survey was one where a low proportion of animals were hauled out, and that 115 animals could have been expected to have been seen, rather than the 77 animals that were actually observed. If the current population is taken to be 100 animals, the sex-ratio and age structure are assumed to be comparable to those for other harbour seal populations and stable, and stochastic effects are ignored, the time for abundance to return to 600 can be estimated. Table 2 contains some estimated recovery times based on different population growth rates. Appendix 1 discusses the limits on available information on the structures of pinniped populations.

Table 2: Number of years for a population to increase from 100 to 600, at various annual growth rates. The final column is the number of additional years required to balance out the decline continuing at 18% for one additional year.

Annual growth rate	Approximate recovery time	Additional years per year of delay
3%	60	6
4.5%	40	4
6%	30	2
12%	16	1.5

Twelve percent is the current growth rate for the Wadden Sea harbour seal population (TSEG, 2011) and often considered to be the maximum sustainable growth rate for pinniped populations. The population in the Wash was growing at 3% *p.a.* before the 1988 phocine distemper epidemic. That increased and was approximately 6% *p.a.* between the 1988 and 2002 epidemics (Thompson *et al*., 2005; Lonergan *et al*., 2007). If the abundance estimates that were made for the Tay in the 1970s are believed to be consistent with the more recent ones, then this population was growing at around 4.5% *p.a*. up to the beginning of the recent decline.

4.3. There is a partial reduction in the problem, rather than a complete cure

This population is declining by around 18% p.a. The accepted "normal" maximum growth rate for pinniped population is 12% *p.a.*. A halving of the impact of the problem could be expected to result in a population growth rate midway between these figures, which is a 3% *p.a.* decline. The effect would need to be reduced by 60% for the population to stabilise at its current level, and more than that to permit it to begin to recover. The situation is much worse if the maximum growth rate is lower. A growth rate of 6% under optimal conditions, similar to that observed in the Wash (Thompson *et al*., 2005; Lonergan *et al*., 2007), would imply that population recovery would require at least 75% of the problem to be resolved. If the maximum achievable growth rate were 3% *p.a*., which may be more representative of Scottish harbour seal populations, then recovery would depend on finding an almost (85%) total solution to the problem.

4.4. The recovering population starts off with a shortage of females.

This would both increase the risk from stochastic variation (i.e. all the females dying) and slow the initial stages of the recovery. Populations starting with more highly skewed sex-ratios would initially grow more slowly and it would take longer for their growth rates to recover to more normal values.

4.5. The local population goes extinct and needs to recolonise from elsewhere.

Harbour seals generally travel relatively short distances, which limits their ability to recover from local extinctions. There is no indication that males and females of this species travel together, which would seem to require multiple colonising events for the establishment of a population.

There are two examples of UK harbour seal populations that became extinct and have recovered to some extent, in the Tees and the Ythan estuaries. The population in the Ythan was removed by shooting in 1979 and 1980. It is not known when the first animals returned, but by the mid 1990s harbour seals were regularly seen in the estuary. The harbour seal population in the Tees is thought to have disappeared at an unknown date in the mid 18th C when large parts of the estuary were reclaimed. Harbour seals recolonized the Tees estuary in the 1970s or early 1980s and the population has grown slowly to reach around 20 to 50 seals (Woods, 2011). The first successful pupping was recorded in 1994.

The more rapid recolonisation of the Ythan estuary may be related to the proximity of small harbour seal haulout groups on the coast 45km to the north. The nearest groups to the Tees are in the Firth of Forth, 200km to the north, or in the River Humber, 170km to the south.

In the event of extinction in the Tay and Eden estuaries the most likely source of colonising harbour seal would be the small populations in the Firth of Forth, 50 to 60 km away, or the animals that haul out north of Montrose, about 40km from the Tay haulouts. However, it is not clear that these groups of animals are actually sufficiently separated to follow different population trajectories. Telemetry tags attached to harbour seals in the Tay and Eden have recorded some of these individuals hauling out in the Firth of Forth and around Montrose. Beyond these areas, the next nearest potential sources of immigrants to the SAC would be the Moray Firth or the Tees and Humber estuaries, so reestablishment of the population might take a long time.

5. Conclusion

- If current trends continue, harbour seals are likely to effectively disappear from the Firth of Tay and Eden Estuary well within the next 20 years.
- The, currently unidentified, cause of the decline must be reducing adult survival
- If the cause is immediately identified and rectified, recovery of the population to the abundance when the SAC was designated is likely to take at least 40 years.
- Partial removal of the problem will have limited benefits.
- There are unlikely to be any long-term benefits from introducing or reintroducing additional individuals while the problem persists.

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Appendix 1: Estimating the structure of pinniped populations.

Pinnipeds are not monogamous; the sexes often haul out in different locations and only females care for pups. Some species, such as the grey seal, show lekking behaviour, with males holding temporary small territories on breeding colonies (Perrin *et al*., 2008). Harbour seals do not form such obvious breeding aggregations, and it is not clear how mate choice occurs. There is no reason to suspect the existence of long-term pairbonds. Therefore, unless a shortage of food lowers fecundity, the number of pups born in a harbour seal population will be proportional to the number of mature females present. This implies that the growth rates of populations containing high proportions of males or juveniles will be lower than for those mainly consisting of adult females, and some evidence for that effect has been found (Harkonen *et al*., 1999).

Estimation of the structure of a population involves two things: identification of a representative sample of animals, and determination of the characteristics of those animals. The first of these steps is the more difficult.

Very small animals are obviously young, but some one-year olds are similar in length to small adults (Harkonen and Heidejorgensen, 1990). Large mature males are relatively easy to distinguish, though the species is less sexually dimorphic than many other pinnipeds (Perrin *et al*., 2008). Individuals seen suckling, or caring for, pups are clearly female. However, that leaves a large proportion of the population whose characteristics cannot be determined remotely for most of the year.

It is possible to determine an animal's sex from analysis of the scats it leaves, but moving from there to estimating the structure of a population is seldom practicable, in any species. Most of the available data on the structure of pinniped populations have therefore come from handling live animals or carcasses. Sex is straightforward to determine; maturity can be determined from hormone levels or physical measurements; and sections through an extracted tooth can be used to estimate each individual's age.

Telemetry studies show that each individual harbour seal hauls out at only a small subset of the suitable locations available to it. Observations, and captures of animals, at haulouts show that these are often largely segregated, with different components of populations using different locations (Harkonen *et al*., 1999; SMRU *unpubl*.). That makes it difficult to identify a suitable set of locations to observe or sample. The problem is exacerbated by difficulties in access to some haulout sites, locations that could be preferentially used by certain demographic groups.

Stranded carcasses provide an alternative source of data, but, since only a small proportion of carcasses are found, introduce another set of potential biases. Probably the most informative estimate of the demographic parameters and structure of a harbour seal population comes from carcasses washed ashore in the Kattegat-Skagerrak, in Scandanavia, during the 1988 phocine distemper epidemic (Harkonen and Heidejorgensen, 1990). Those waters are largely enclosed, forming the channel connecting the Baltic to the North Sea, and the disease caused embolisms that kept the carcasses afloat. More than half the animals died, limiting the selectivity in the disease's sampling of the population. Annual survival of adult males was estimated at 91%, based on an assumed population growth rate of 11% *p.a.*. Adult female survival was slightly higher, but did not fit an exponential pattern. Those results suggest that slightly more than half the population was female. Females were estimated to give birth first at age 4 or 5. If it is assumed that female survival was 0.92 at all ages, then around 75% of females would be mature, but this estimate has limited value, given that it assumes an exponential pattern of mortality. A survival rate of 0.88 or 0.96 would imply 60% or 90% of the females were mature.

Similar problems have occurred in the estimation of the demographic structure of grey seal populations, though many more data are available. Until recently models of the UK population used an estimate that this population contained 0.73 males per female. Recent re-examination of available data revised that ratio, suggesting it was much lower and quite imprecise. There now seems to be a 95% chance that the true value lies in the range 0.025-0.56 males per female. The same work suggested that, while the annual survival rate for adult female grey seals cannot be much lower than 90%, insufficient data are available to describe it more precisely than that (SMRU, *unpubl.*).

The estimates of sex-ratio and adult survival rates for grey seals were based on examination of more than 300 carcasses, so it may not be surprising that it is difficult to estimate the demographic structure of the small population of harbour seals in the Tay and Eden Estuaries SAC that is currently experiencing a rapid and unprecidented decline. There are probably now too few animals in that area to allow useful estimates of the population's structure without causing unacceptible levels of disturbance. Even the approach, of providing two bracketing sets of estimates assuming either an equal sex-ratio or an almost entirely female population, (Lonergan *et al*., in press) would not cover the possibility that the cause of the decline is additional mortalities affecting only females.

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Marine distribution of grey & harbour seals around the UK

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Summary

The way that grey and harbour seals use their marine geographical environment (i.e. spatial usage) appears to be different. When both species haul-out at similar locations, such as Orkney, harbour seals stay close to the coast and their haul-out sites, whereas grey seals move further afield. So, even though both species are characterised as central place forages they appear to have different spatial distribution strategies. This behaviour was modelled for each species to produce UK-wide maps on a fine-scale by linking two decades of telemetry and terrestrial count data to produce population-level estimated usage. Uncertainty was propagated through the analysis and quantified as standard deviation contours on the usage maps. These provide a level of certainty and are particularly useful when focusing on fine-scale features of the maps.

Introduction

Fisheries have historically regarded seals as a potential threat to economically important fish stocks and a number of legislative acts now protect seal species, while working with the fishing industry to protect their livelihood. Grey and harbour seals are both listed in Annex II of the European Habitats Council Directive 1992 (EHCD) (Council Directive 92/43/EEC on the Conservation of natural habitats and of wild fauna and flora) which requires member states to protect grey and harbour seals to maintain 'favourable conservation status', meaning that populations must have long term stability and viability, sustained natural range, and that an adequately large habitat is maintained for the population (JNCC, 2010). This has led to 24 Special Areas of Conservation (SAC) around the UK (14 in Scotland) where grey and harbour seals (as Annex II species) are the qualifying reason or feature for selection (JNCC, 2012). Marine protected area (MPA) design commonly focuses on identifying areas with a high abundance of apex predators when they are the focus of the MPA and spatial and/or temporal maps form an accessible platform for MPA design (Hooker *et al.*, 2011). It is therefore important to provide accurate estimates of spatial usage with quantifiable precision to inform future management plans.

Likewise, recent expansion in proposed renewable energy developments of offshore tidal, wave and wind power particularly around Scotland means that spatial distribution and abundance of seals are needed as inputs into Environmental Impact Assessments when considering placement and potential impacts of commercial development.

Spatial maps provide insights into species distributional ranges, comparisons between these ranges, and provide a layer of information to link other datasets such as fisheries and prey data, enabling spatial and/or temporal overlap studies. This paper presents up-to-date fine-scale usage maps of grey and harbour seals around the UK with corresponding uncertainty estimates, utilising 20 years of telemetry and aerial survey data.

Methods

Count data

Aerial surveys are conducted each year by Sea Mammal Research Unit (SMRU) and funded primarily by the National Environmental Research Council (NERC), Scottish Natural Heritage (SNH) and Natural England (NE). Grey and harbour seals are surveyed during August when harbour seals are found in moulting aggregations and grey seals are dispersed in haul-outs along the coast.

Over a number of consecutive years the entire Scottish coastline is surveyed and counts are marked using OS Landranger maps (1:50,000) to within an accuracy of 50m. Data from 1996-2010 surveys were used in the analysis.

Fixed wing aerial surveys were also completed over selected areas of the Scottish and English east coasts funded by NERC, SNH, NE and the Department of Energy and Climate Change (DECC). The Moray Firth, Firth of Tay, Donna Nook, The Wash in East Anglia, and the Thames estuary were surveyed and counts between 1988 and 2009 were used in the analysis.

Harbour seals in southern England around Chichester & Langstone harbours are monitored through public sightings and by the Chichester Harbour Authority. They provide a source of ground counts, and August sightings from 1999-2011 were used.

An aerial survey was conducted by SMRU in Northern Ireland in 2002, funded by the Northern Ireland Environment Agency. The same protocol was used as the Scottish aerial surveys. Additional aerial surveys were undertaken by SMRU Ltd around the Strangford Lough area in 2006, 2007, 2008 and 2010 and were funded by Marine Current Turbines Ltd. In 2003 an aerial survey of the Republic of Ireland was carried out by SMRU, funded by the Department of Arts, Heritage, Gaeltacht and the Islands.

Welsh counts were taken from Grey seal distribution & abundance in North Wales, 2002-03. The ground counts extended over all months and did not follow the same protocol as the aerial surveys.

Survey counts from France were taken from Hassani *et al.*, 2010. These are yearly ground counts of harbour seals from 1986-2008, across three locations: Baie de Somme, Baie de Veys, and Baie de Monte Saint Michel. Figures 1 and 2 show the locations of aerial survey and ground counts used, colour coded by country.

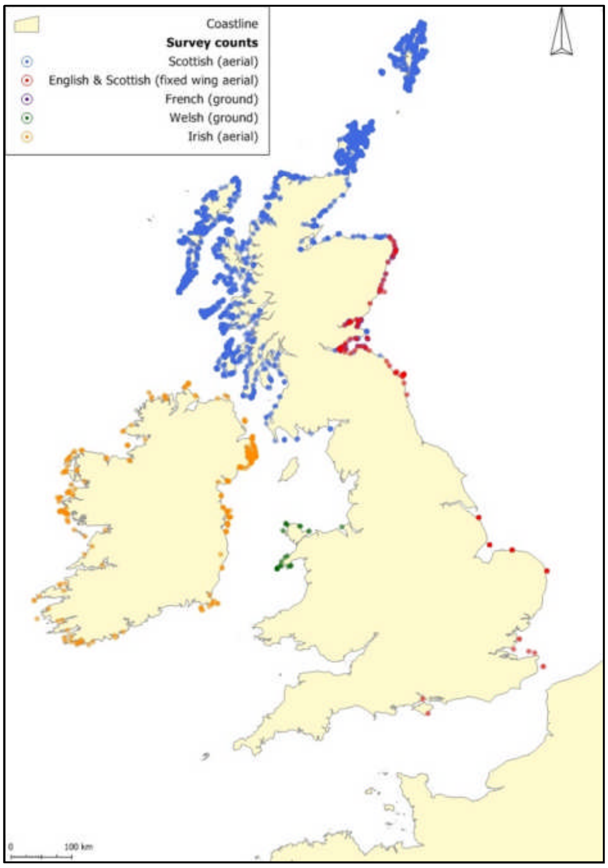


Figure 1 Grey seal aerial survey & ground counts.

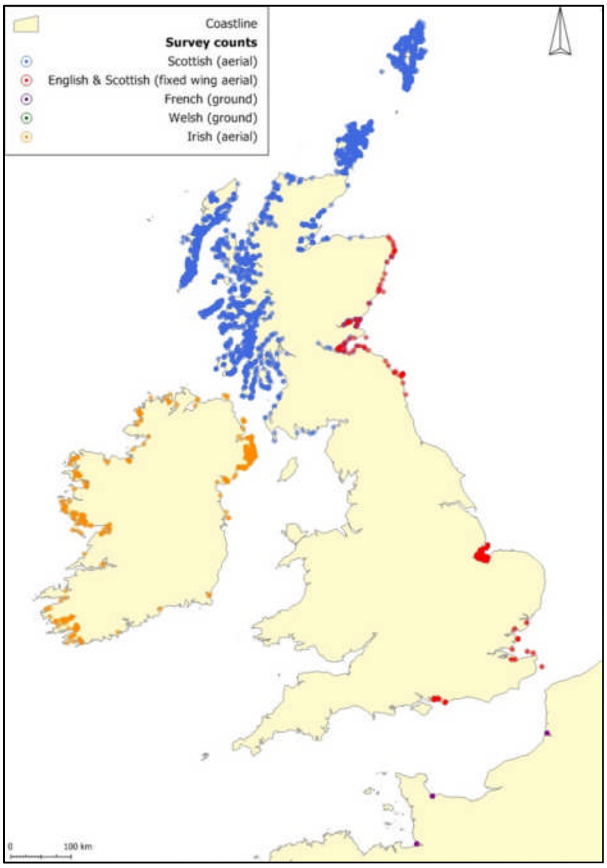


Figure 2 Harbour seal aerial survey & ground counts.

Telemetry data

Telemetry data from grey and harbour seals have been collected by SMRU since 1988. These are from two types of logging devices: Satellite Relay Data Logger (SRDL) tags developed by SMRU use the Argos satellite system and were deployed between 1988 and 2010. GPS phone tags that use the GSM mobile phone network with a hybrid Fastloc protocol (McConnell *et al*., 2004) have been deployed since 2005. Telemetry data were selected from the SMRU database by species and processed through a set of data-cleansing protocols to remove null and missing values, duplicated records and ineligible data (Russell *et al.*, SCOS briefing paper 11/17). Of the 425 telemetry tracks used, 229 were from grey seals (Table 1) and 196 were from harbour seals (Table 2). All available data were used and age, sex and life-stage were not disaggregated for the purposes of the analysis.

Year	Tag type	Number of tags	Sex ratio (m:f)	Age ratio (adult:pup)
1991	Argos	5	4:1	5:0
1992	Argos	12	8:4	12:0
1993	Argos	3	2:1	2:1
1994	Argos	4	2:2	0:4
1995	Argos	20	14:6	14:6
1996	Argos	20	8:12	20:0
1997	Argos	8	4:4	8:0
1998	Argos	24	17:7	24:0
2001	Argos	11	6:5	1:10
2002	Argos	12	5:7	2:10
2003	Argos	22	14:8	22:0
2004	Argos	26	10:16	26:0
2005	Argos	9	4:5	9:0
2006	Argos	2	1:1	2:0
2008	Argos/GPS	19	9:10	19:0
2009	GPS	12	2:10	7:5
2010	GPS	20	7:13	0:20

Table 1. Summary of grey seal telemetry tracks used.

Year	Tag type	Number of tags	Sex ratio (m:f)	Age ratio (adult:pup)
2001	Argos	10	5:5	10:0
2002	Argos	5	4:1	5:0
2003	Argos	36	15:21	36:0
2004	Argos	35	18:17	30:5
2005	Argos	21	12:9	21:0
2006	Argos/GPS	52	33:19	52:0
2007	Argos/GPS	2	1:1	2:0
2008	GPS	14	7:7	14:0
2009	GPS	10	3:7	10:0
2010	GPS	10	8:2	10:0
2011	GPS	1	0:1	1:0

Table 2. Summary of harbour seal telemetry tracks used.

Treatment of positional error

Positional error, varying from 50m to over 2.5km (Argos User's Manual, 2011), affects all Argos telemetry points leading to a loss in fine-scale detail. The range of positional error is defined by the number of uplinks received during a satellite pass. Errors are assigned to six location classes: '0', '1', '2' and '3' indicate four or more uplinks have been received for a location, 'A' denotes three uplinks, and 'B' denotes two uplinks (Vincent *et al*., 2002). Because seals spend the majority of their time underwater, uplink probability is reduced and so over 75% of the telemetry data have location class error 'A' or 'B'.

There are many approaches to addressing the problem, ranging from simple moving average smoothers to elaborate state-space models, but none have offered a comprehensive solution combining automation, computational speed, precision and accuracy. Since we are interested in large-scale population-level inferences rather than high-resolution individual-based insights we opted for a Kalman filter (Royer & Lutcavage, 2008; Patterson *et al*., 2010; Roweis & Ghahramani, 1999) using a linear Gaussian state-space model to obtain estimates, accounting for observation error. This has been developed in-house to give flexibility and fast processing times. Argos data were first speed-filtered (McConnell *et al*., 1992) at $2ms^{-1}$ to eliminate outlying locations that would require an unrealistic travel speed. Observation model parameters were provided by the location class errors described above, and process model parameters were derived from Vincent *et al*. (2002).

GPS tags are more accurate than Argos tags, and 95% of these data have a distance error of less than 50m. However, occasional errors do arise and these data were excluded from the analysis by removing data with residuals that were either 0 or greater than 25, and removing locations with less than 5 satellite fixes (Russell *et al*., SCOS briefing paper 11/17).

Haul-out detection

SRDL and GPS telemetry tags record the start of a haul-out event once the tag sensor has been continuously dry for 10 minutes. This event ends when the tag has been continuously wet for 40 seconds. Haul-out event data were combined with positional data and assigned to geographical locations. In the intervening period between successive haul-out events, a tagged animal was assumed to be at sea (if the tag provided such information) or in an unknown state (if the tag did not).

Haul-out aggregation

Haul-out sites were defined by the telemetry data as any coastal location where at least one haul-out event had occurred, aggregated into 5km square grids.

Trip detection

Individual movements at sea were divided into trips, defined as locations between haul-out events. Return trips have the same departure and termination haul-out site, whereas for transition trips, seals haul-out at a different termination site to the departure site after a period at sea. A haul-out site was assigned to each location in a trip. Return trips were attributed to the departure haul-out. Transition trips were divided temporally into two equal parts and the corresponding telemetry data were attributed to departure and termination haul-outs.

Kernel smoothing

Kernel smoothing (KS) is a statistical technique, which fits a smooth spatial usage surface to a set of positional data (Matthiopoulos, 2003). The KS (Chacon & Duong, 2010; Duong & Hazelton, 2003; Wand & Jones, 1994; Wand & Jones, 1995) library in R was used to estimate the spatial bandwidth of the 2D kernel applied to the telemetry data.

Information content weighting

To account for individual variation in the telemetry points collected from each animal, indices of information content were devised using data from the whole of the UK. For each species, models were built using a response variable of rate of discovery, defined by the number of new 5km grid cells an animal 'discovers' during the lifespan of the telemetry tag. This rate was modelled as a function of the number of received telemetry locations for an animal, tag lifespan and whether the tag was Argos or GPS. The intercept was set to zero and a Poisson distribution with a log-link function was used. The models used Generalised Additive Models (GAMs) utilising the R library MGCV (Wood, 2011; Wood, 2006).

Figure 3a shows a boxplot of grey seals tag type vs. discovery rate for total usage. The mean number of grid cells discovered throughout a tag's lifespan are shown by red triangles (Argos = 178, GPS = 335). A Welch two-sample t-test gave a significant difference between the means at a 95% confidence level. This was driven by a significantly higher tag lifespan (Figure 3b; Argos = 2896 hours, GPS = 3875 hours), and higher uplink rate per hour (Figure 3c; Argos = 0.36, GPS = 1.22). The Argos tags show smaller variation in the number of locations per hour because they were regularised at 6 hourly intervals, as well as keeping the original locations in the data.

Figure 4a shows a boxplot of harbour seals tag type vs. discovery rate for total usage. The mean number of grid cells discovered throughout a tag's lifespan are shown by red triangles (Argos = 67, GPS = 18). A Welch two-sample t-test gave a significantly higher mean for Argos data at a 95% confidence level. This was driven by a significantly higher tag lifespan (Figure 4b; Argos = 2987 hours, GPS = 2169 hours) although the GPS tags have a higher uplink rate per hour (Figure 4c; Argos = 0.45, GPS = 0.85).Number of locations, tag lifespan, and tag type (Argos or GPS) were significant and explained 43.2% and 27.9% of variation in the data for grey and harbour seals respectively.

Figures 5a and 6a show total usage fitted values vs. observed discovery rate. Figures 5b, 6b, 5c and 6c show the GAM smoothing curves for tag lifespan and number of telemetry locations. Fitted values were normalised and used to weight the contribution of different animals to estimate usage associated with each haul-out location. This approach reduced the importance of data-poor animals, whilst simultaneously not overstating the contribution of animals with heavily auto-correlated observations.

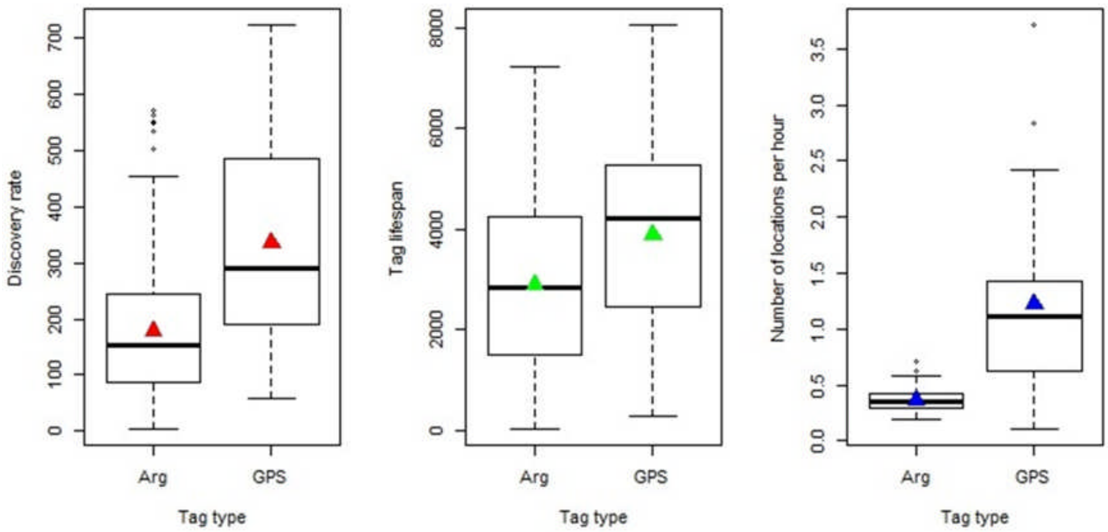


Figure 3. Boxplots showing significant differences between tag types for grey seals. Coloured triangles represent mean values, thick black lines are median values, boxes are interquartile ranges, dotted lines show minimum and maximum values. (L-R): 3a. Discovery rate; 3b. Tag lifespan; 3c. Number of locations per hour.

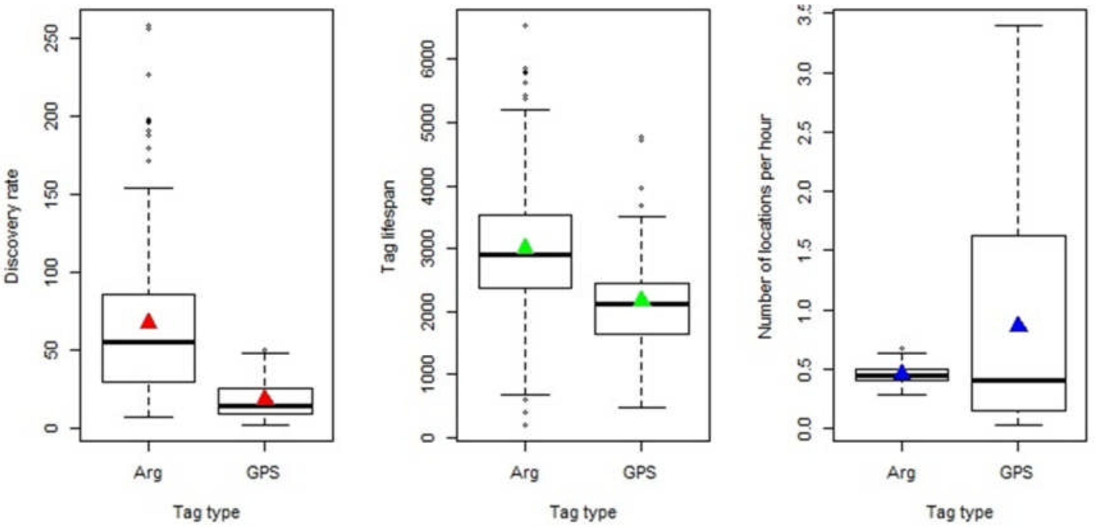


Figure 4. Boxplots showing significant differences between tag types for harbour seals. Coloured triangles represent mean values, thick black lines are median values, boxes are interquartile ranges, dotted lines show minimum and maximum values. (L-R): 4a. Discovery rate; 4b. Tag lifespan; 4c. Number of locations per hour.

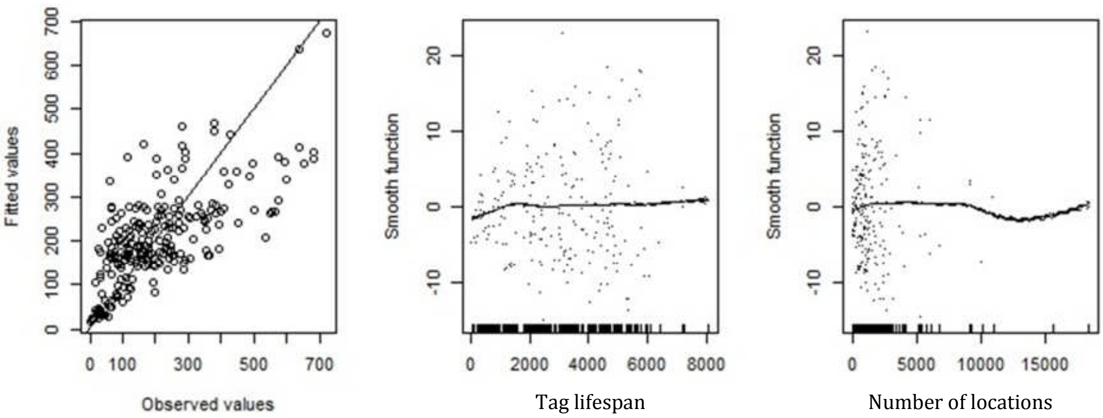


Figure 5. GAM model deriving 'information content' by individual grey seal. (L-R): 5a. Observed vs. fitted values; 5b. Tag lifespan smoothing curve; 5c. Number of telemetry locations smoothing curve.

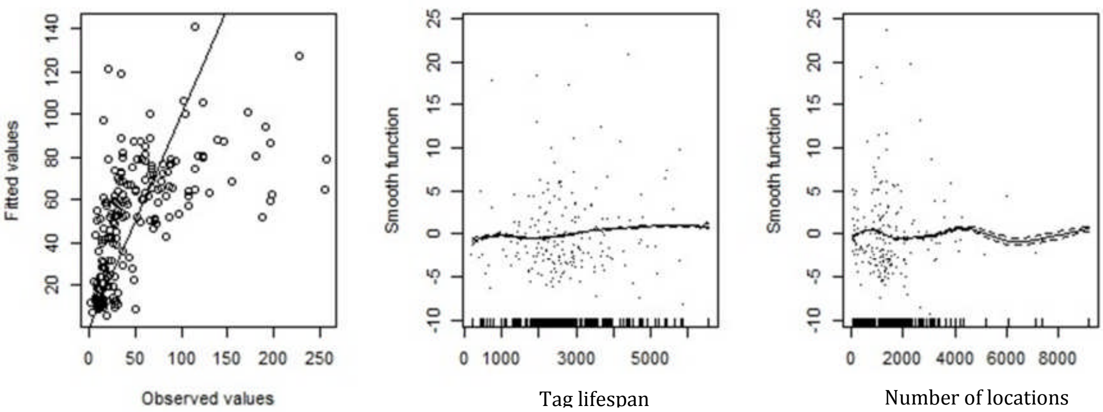
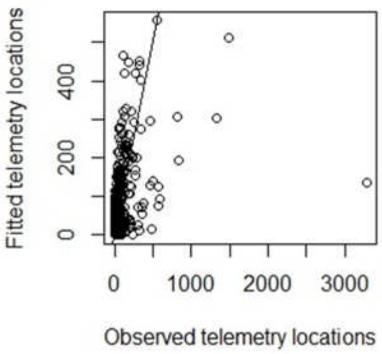


Figure 6. GAM model deriving 'information content' by individual harbour seal. (L-R): 6a. Observed vs. fitted values; 6b. Tag lifespan smoothing curve; 6c. Number of telemetry locations smoothing curve.

NULL (accessibility) model

To account for areas in the maps where aerial survey data were present but telemetry data were not, null maps of estimated density were produced for each species. GLMs were used to model the number of telemetry locations associated with each haul-out. This count was modelled using at-sea distance from the haul-out to represent accessibility by animals to each haul-out, and the distance to the shore to represent accessibility to the coast. A sub-sample of adult tracks from each species were selected and quasi-Poisson distributions with log link functions were fitted. Figure 7 shows the observed vs. fitted number of telemetry locations associated with each haul-out for (a) grey seals and (b) harbour seals.



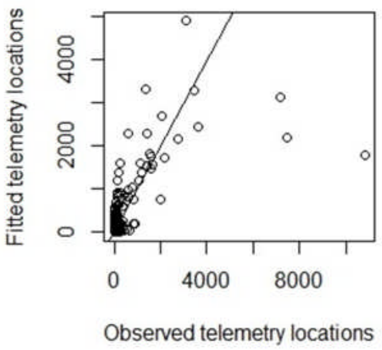


Figure 7. GLM models deriving null usage. Observed number of telemetry locations vs. fitted locations for: 7a. Grey seals; 7b. Harbour seals.

Quantifying uncertainty

Several types of uncertainty were accounted for at individual animal and population level.

Within haul-out

For each species, Linear Models (LMs) were built to estimate variance. All haul-outs with more than 7 animals associated with them were used. This was the minimum number of animals needed to bootstrap each haul-out, and was tested experimentally. The response variable was logged variance, and the covariates were: sample size (number of animals associated with a haul-out) and logged estimated mean density of seals weighted by information content. At-sea kernel smoothed densities were bootstrapped 500 times for each haul-out, and sample size was sampled with replacement and logged, to produce estimated logged variance and logged mean densities. The models used both covariates without an interaction term and explained 100% of the variation in the data.

Estimated mean densities in the null maps were produced by setting sample size to 0 in the uncertainty model to reflect that no tagged animals went to these haul-outs.

Aerial survey & population level

Several types of uncertainty are associated with aerial surveys and scaling to population level. Observational errors occur in surveys due varying weather conditions, aircraft altitude, and accuracy in recording animal locations. Sampling errors occur because surveys by their nature are instantaneous counts in time. These errors are mitigated as much as possible through survey design and repeat surveying. Errors also occur when scaling to population estimates as a population mean haul-out percentage was used (Lonergan *et al.*, submitted; Lonergan *et al.*, 2011). These errors were accounted for by using a derived likelihood density distribution and applying this to each haul-out site based on a given population estimate and the aerial survey counts.

Parameters for the beta function in the likelihood function were calculated using the mean proportion of time each seal species spends hauled-out along with their corresponding confidence intervals (Lonergan *et al.*, submitted; Lonergan *et al.*, 2011).

$$\alpha = \frac{\mu}{\sigma^2}(\mu - \mu^2 - \sigma^2) \quad \text{and} \quad \beta = \frac{1-\mu}{\sigma^2}(\mu - \mu^2 - \sigma^2)$$

Where*:*

μ = mean seal population hauled-out at any point in time
σ^2 = variance in seal population hauled-out at any point in time

The density distribution likelihood distribution was then derived as:

$$Likelihood = \frac{\prod_{k=N_i-m_{ij}-1}^{N_i-m_{ij}+\beta-1} k}{\prod_{k=N_i+1}^{N_i+\propto+\beta-1} k}$$

Where:
N_i = Seal population of i[th] haul-out
m_{ij} = Number observed on i[th] haul-out on j[th] survey

Population mean and variance of each haul-out site were estimated by sampling with replacement from the likelihood density and taking the mean and variance from that sample.

The population and within haul-out means and variances for each haul-out were combined using formulas for the sum of independent variables.

$mean = E(X)E(Y)$

$variance = E(Y)E(Y)Var(X) + E(X)E(X)Var(Y) + Var(X)Var(Y)$

Analysis

To create maps of at-sea usage all grey and harbour seal telemetry data from the SMRU database were put through a series of data cleansing protocols to remove unusable data. Argos data were spatially interpolated to 6 hour intervals using a Kalman filter and merged with GPS data.

A grid consisting of 5km squares was created to extend to the limits of the telemetry tracks and overlaid onto the data. Haul-out detection and aggregation were applied to the data at 5km resolution. After spending time at sea an animal could either return to its original haul-out (classifying this part of the data as a return trip), or move to a new haul-out (giving rise to a transition trip).

At-sea data (i.e. when animals were not hauled-out) were then kernel smoothed. A bandwidth was estimated for each animal. Each animal/haul-out combination was kernel smoothed using the estimated bandwidth to produce separate animal/haul-out association distribution maps.

Each animal/haul-out map was multiplied by the normalised Information Content Weighting and all maps connected to each haul-out were aggregated and normalised. Within haul-out uncertainty was predicted and the aggregated usage map and this uncertainty were combined with the previously estimated population mean and variance. The mean usage was then multiplied by the total proportion of time animals spent at-sea to calculate at-sea usage only. Usage and variance by haul-out were aggregated to a total at-sea usage and variance map for each species.

Null maps were constructed for each haul-out with no associated telemetry data. The null models were fitted for each species to estimate usage, then normalised, and weighted by the mean proportion of time animals spend not hauled-out. Within haul-out variance was estimated by setting the sample size of the uncertainty model to 0. The mean and variance were scaled to population size by combining with the population estimate mean and variance of each haul-out. These were aggregated to the total at-sea usage map for each species.

Results

Figure 8 shows the estimated at-sea spatial usage of grey seals around the UK. The map can be interpreted as the average number of seals in each $5km^2$ grid square at any point in time. For example, a yellow square denotes, on average, between 25 and 50 grey seals will be within that grid square at any point in time.

White contour lines denote standard deviation from the mean as a measure of uncertainty around the estimated usage. Labels show the value of standard deviation at each contour as the square root of the estimated variance.

The majority of usage is concentrated around Scotland, reflecting the distribution of grey seals around the UK (88% of UK grey seals breed in Scotland, SCOS 2011).

The standard deviation contours are a function of variation in aerial survey counts and the number of tagged animals associated with a haul-out. Therefore, they are a measure of aerial survey and tagging effort in each $5km^2$ grid.

Similarly, figure 9 shows the estimated at-sea spatial usage of harbour seals around the UK with standard deviation denoted by white contour lines.

Discussion

The spatial extent to which harbour seals use their geographical environment at-sea appears to be less than grey seals. For instance, on the east coast of England a large colony of grey seals at Donna Nook (figure 8) regularly travel 230km out to sea from their haul-out site. In contrast, harbour seals in The Wash (figure 9), south of Donna Nook regularly travel 165km out to sea (30% less than grey seals). More generally, harbour seals spend little time at the continental shelf to the west of the UK, whereas grey seals utilise areas all along the shelf.

The telemetry movements of harbour seals underpinning the usage maps show that they although they do not travel so far offshore as grey seals (with exception of some individuals, (Sharples *et al.*, 2012)), they show considerable movement parallel to the coast, resulting in concentrated patches of high at-sea usage close to the coast. By contrast grey seals have continuous high spatial usage throughout larger areas, not only around haul-out sites, but also at-sea, indicating possible foraging patches (Thompson *et al.*, 1996).

Although the analysis does not infer changes in population dynamics through temporal representation, it shows differences in the way the two species use their marine environment, which can inform the mechanisms behind the contrasting dynamics of increasing grey seal and decreasing harbour seal populations.

Acknowledgements

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Arts, Heritage, Gaeltacht and the Islands; Countryside Council for Wales & Welsh Assembly Government; SMRU Ltd, National Environmental Research Council (NERC), Scottish Natural Heritage (SNH); Natural England (NE), Department of Climate Change (DECC).

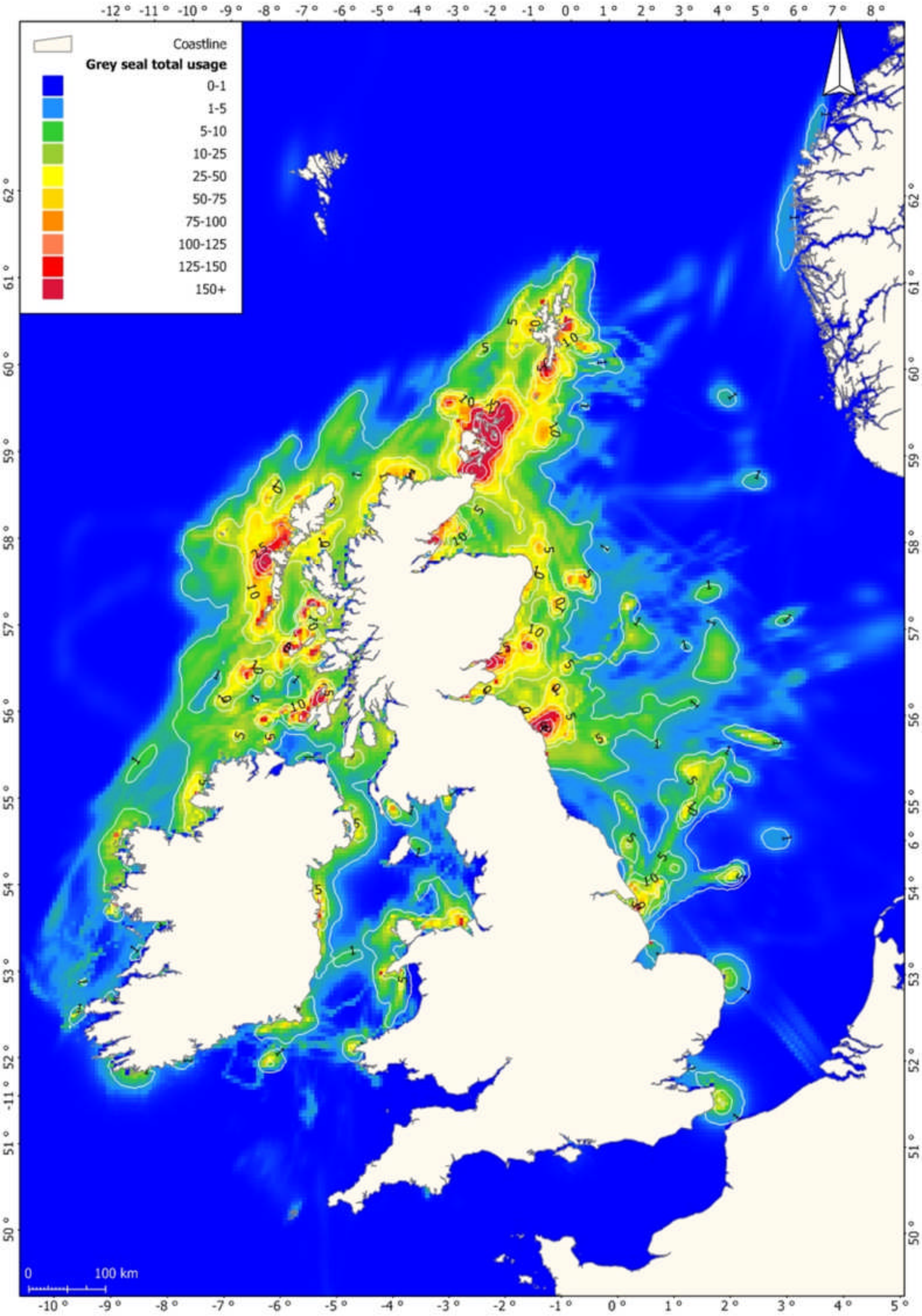

Figure 8. Estimated grey seal total (at-sea & hauled-out) usage around the UK. White contours show standard deviation from mean usage as a measure of uncertainty.

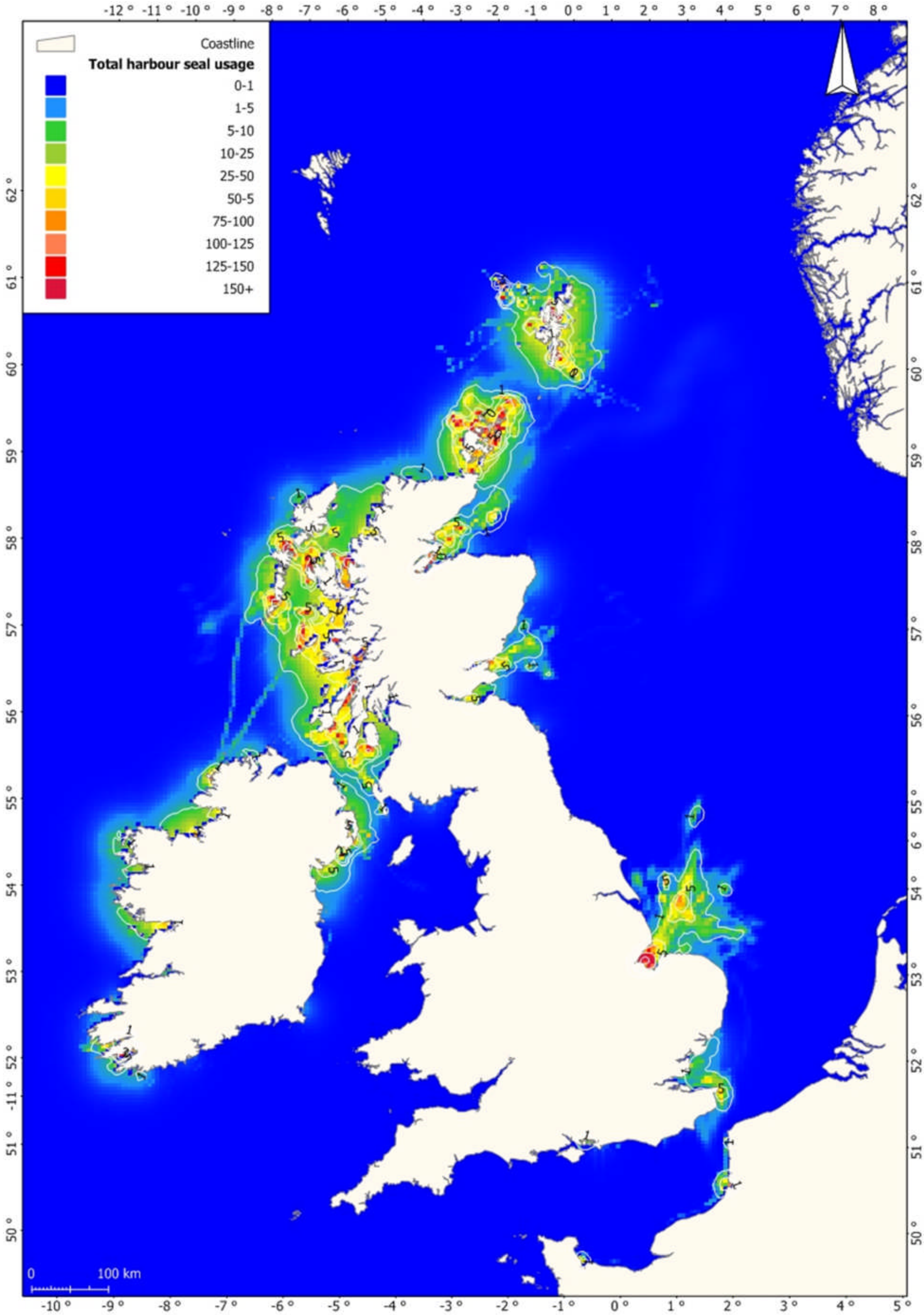

Figure 9. Estimated harbour seal total (at-sea & hauled-out) usage around the UK. White contours show standard deviation from mean usage as a measure of uncertainty.

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Pup to adult photo-ID: evidence of pelage stability in grey seals

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Summary

The use of automated software to match pelage pattern in adult female grey seals is an established technique. Pelage pattern in juvenile female grey seals is known to change in the first few years of life. However, there is evidence to suggest that despite that change, the stability of pelage pattern from weaning through to adulthood is sufficient to allow the use of automated software to make matches. This provides an opportunity for early survival and recruitment studies.

Introduction

Photo-identification of adult female grey seals is an established technique for re-sighting individuals both on land (Redman, 2002) and at sea (Hiby & Lovell, 1990). However, the re-sighting of individuals from weaning to adulthood has historically relied on marking techniques such as flipper tagging and/or branding (Bowen & McMillan, 2007; Pomeroy *et al.* 2010). The stability of pelage pattern in adult female grey seals is evident from the various studies that rely on this as a method of identification (Hiby *et al.* 2007; Pomeroy et al. 2005). SCOS Briefing Paper 10_HP summarised our approach to automating photo-identification of adult female grey seals using program ExtractCompare. This method is now described in detail in “Automated identification of grey seals using pelage patterns from multiple body regions”, submitted to Methods in Ecology and Evolution. In this briefing paper we address the issue discussed in SCOS Briefing Paper 11_HP that the current photo-ID catalogue excludes photographs of weaned pups. Pelage pattern in juvenile female grey seals has been shown to change over the first few years of the animals’ life (Vincent *et al.* 2001). Here we investigate whether that change invalidates the use of automated photo-identification. We applied the same technique used for automated photo-identification of adult females to images of weaned pups that have recruited back to their natal site and have been photographed as adults.

Methods

Neck pattern extracts from weaned pup images

A number of adult females that breed on the Isle of May, and are part of the photo-ID catalogue at SMRU, have been photographed on the island previously as weaned pups. We examined images of 20 individuals whose identity could be verified by a secondary means such as a flipper tag, pit tag or brand. Where images of weaned pups were of sufficient quality pattern extracts were taken from either side of the neck region using program ExtractCompare (Figure 1a). The methodology used to take these neck pattern extracts was the same as that currently used for adult females (Figure 1b). This allowed for comparisons to be made between neck pattern extracts taken from images of the same individual as a weaned pup and then again as a breeding adult.

Comparison process

Photographic surveys carried out during the breeding season at the Isle of May, Fast Castle and Donna Nook provide images of adult female grey seals from which neck pattern extracts have been taken using program ExtractCompare. The SMRU photo-ID catalogue contains 3261 distinct IDs of adult females photographed at one of these sites between 2007 and 2011 that are represented by at least one neck pattern extract. Of those 3261 distinct IDs, 1297 are represented from the left side only, 1313 from the right side only and 651 from both sides. This means that each left side neck extract from an image of a weaned pup was compared to 1297+651=1948 adult IDs. Similarly, each right side neck extract from an image of a weaned pup was compared to 1313+651=1964 adult IDs. Each weaned pup was known to be represented at least once as an adult when comparisons were made.

When neck pattern extracts from an individual weaned pup have been compared to those from adults program ExtractCompare lists, in rank order of similarity, the adult IDs most likely to match to newly entered extracts. Images of the weaned pup are then presented alongside the ranked images of adult females, with rank

1 being most similar. At this point visual confirmation of a match is required by the user. In this study we visually checked down to rank 20, consistent with the methodology for visually checking matches between images of adults.

Results

Neck pattern extracts from weaned pup images

Of the 20 individuals included in this study seven provided images from weaning to adulthood that were judged to be of sufficient quality to allow neck pattern extracts to be taken using program ExtractCompare. Table 1 summarises the number of neck extracts taken from each individual both as a weaned pup and as an adult. Images of 13 individuals photographed as weaned pups and as adults were available but weren't used either because the image quality was too poor or not enough pelage pattern was visible.

Comparison process

Neck pattern extracts taken from images of seven individuals as weaned pups resulted in five matches when compared to existing adult neck pattern extracts. Four of the five matches were made at rank 1 and one at rank 4. Neck pattern extracts taken from images of two of the seven individuals as weaned pups failed to match to neck extracts taken from images of the same individuals as adults (Table 1).

Discussion

Preliminary results presented in this briefing paper suggest that pelage pattern in some female grey seals is sufficiently stable from weaning to adulthood to allow automated photo-ID to be used. In the case of re-sighting adult females flipper tagged as pups program ExtractCompare provides a tool that could aid in confirming the identity of individuals where it has not been possible to read the tag. This is particularly important at the Isle of May where there is an ongoing program of flipper tagging grey seal pups. These results also demonstrate the potential of using pelage pattern as a natural marker for capture-mark-recapture (CMR) studies in juvenile grey seals. In previous studies that have estimated survival (Hall *et al.* 2001) and recruitment (Pomeroy *et al.* 2010) in juvenile grey seals, artificial markers such as flipper tags have been used. Photo-ID may provide a means of deriving similar estimates using a non-invasive technique. However, to be able to use an automated method to make such estimates quantification of the false rejection rate (FRR) of images of the same seal is required. A quantitative assessment of the performance of program ExtractCompare will only possible where, given an adequate sample size, the ID of animals photographed as pups and then again as adults can be verified as being the same by a secondary means. The long-term study at the Isle of May where grey seal pups that have flipper tags applied are routinely photographed should provide those data. As those pups recruit back to the Isle of May many will be photographed during regular surveys carried out annually during the breeding season. However, when flipper tagged pups recruit to other breeding colonies where regular photographic surveys are not carried out those data will be missed. Recruitment at the Isle of May has been low from 1993 onwards while a nearby colony (Fast Castle) has shown a steady growth over the same period (Pomeroy *et al*. 2010; Duck & Morris, SCOS 2010).

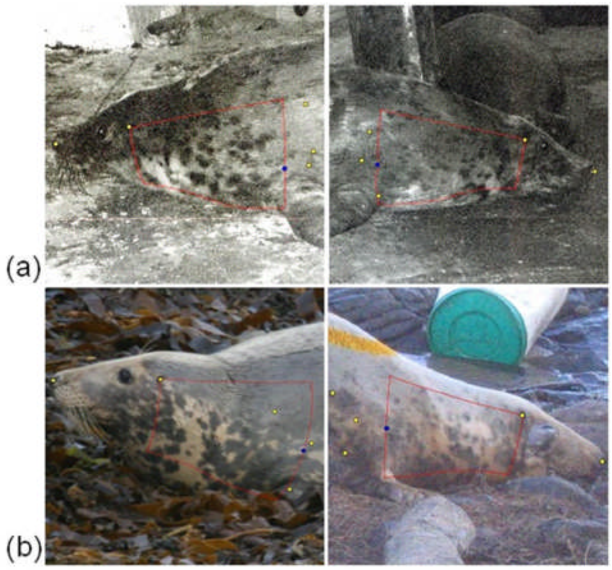

Figure 1. Left and right images of female tag 49526 as a weaned pup in 1997 (a) and as an adult in 2007 (right) and 2008 (left) (b). Pattern extraction areas are delineated in red

Conclusions

The results presented in this briefing paper re-inforce the importance of resighting and photographing adult female grey seals in surrounding colonies that have been flipper tagged and photographed as pups at the Isle of May. Those neighbouring breeding colonies should include at a minimum Fast Castle and the Farne Islands where pups born and flipper-tagged on the Isle of May could recruit as breeding adults. The available sample size of known pup to adult comparisons is expected to increase by focusing efforts to re-sight and photograph individuals with flipper tags. Further, the quality of photographs used in comparisons is expected to improve, especially where digital photographs of weaned pups have been taken. This will allow pattern extracts to be taken from the flank region of the body whereas in this study image quality restricted pattern extraction to the neck region only.

This technique would allow quantification of the FRR of program ExtractCompare for the weaner-adult transition, offering a potential method for obtaining minimum estimations of early apparent recruitment and survival of female grey seal pups.

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Table 1. Shown are the IDs of females that had neck pattern extracts compared using program ExtractCompare. The number of side specific neck pattern extracts taken from images of weaned pups and adults show how each individual was represented before the comparison process was carried out. The rank order of similarity of neck pattern extracts among more than 3200 adult IDs is given where a match was made.

ID	Pup neck extracts (Left)	Pup neck extracts (Right)	Adult neck extracts (Left)	Adult neck extracts (Right)	Matched?
tag 57062	1	1	1	0	Rank 4
tag 57045	1	1	4	7	Rank 1
tag 49419	1	1	1	1	Rank 1
tag 57448	1	1	6	8	Rank 1
tag 49526	1	1	2	2	Rank 1
tag 57024	0	1	2	5	No
pit tag 011874364	1	1	1	1	No

[1+]**Chris Morris, [1]Callan Duck, [1]Mike Lonergan, [2]John Baxter, [3]Stuart Middlemas, [4]Ian Walker**

Method used to identify key seal haul-out sites in Scotland for designation under the Marine (Scotland) Act Section 117

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Contents

Introduction

Section 117 of the Marine (Scotland) Act 2010 (the Act) provides for Scottish Ministers, after consulting the Natural Environment Research Council (NERC), to designate haul-out sites, which are considered suitable to protect seals from harassment, through an order in the Scottish Parliament. A haul-out site is a location on land where seals haul themselves out to rest. This paper aims to describe the method used to identify and select key seal haul-out sites for the purpose of the Act.

The Sea Mammal Research Unit (SMRU) generally conducts aerial surveys of seals during two different times of the year. The first survey period is during the harbour (or common) seal moult in August and produces minimum counts for harbour seals and grey seals around the entire Scottish coast approximately once every five years. The second survey period is during the grey seal breeding season from mid-September to early December and produces annual pup production estimates for approximately 60 of the main grey seal breeding colonies in Scotland. This represents the best available data with only very limited data available for other times of the year.
SMRU aerial survey methods are described in Appendix E.

The data from these two different survey types were used to create two separate lists of haul-out sites covering all of the existing Seal Management Areas and sub-divisions (Figure 3). One list contains significant harbour and grey seal haul-out sites that were selected using data from the harbour seal moult surveys (‘Designated Seal Haul-out Sites’). The second list contains significant grey seal breeding colonies (‘Designated Seasonal Seal Haul-out Sites’) that are not already included in the first list. It is proposed that sites on the first list will be protected year-round under the Act, whereas sites on the second list will be protected only during the grey seal breeding season from September through December.

This document describes the methodology for using aerial survey data to identify high density areas (‘hotspots’) for seals around the Scottish coast, which can be used to define seal haul-out sites/areas around these hotspots and to select significant haul-out sites for designation using a standardised procedure.

The process also included reviewing all the seal haul-out sites suggested by respondees to a Scottish Government consultation in spring 2011. This review indicated that no significant sites were missed and that a number of those meeting the criteria had indeed already been included.

Datasets and software used

Data collected during August helicopter surveys between 1996 and 2010 were used to identify haul-out sites. The most recent data available from grey seal breeding surveys (i.e. 2005-2010) were used to identify additional seasonal sites for grey seals.
OS OpenData coastline shapefiles (2010) were used in *Manifold GIS 8.0* for identifying sites and defining site extent. *EDINA Digimap ShareGeo* shapefiles (2011) were used to define final site boundaries. Individual actions used in *Manifold GIS 8.0* are summarised in Appendix F. The final site selection process was carried out using *MS Excel 2010.*

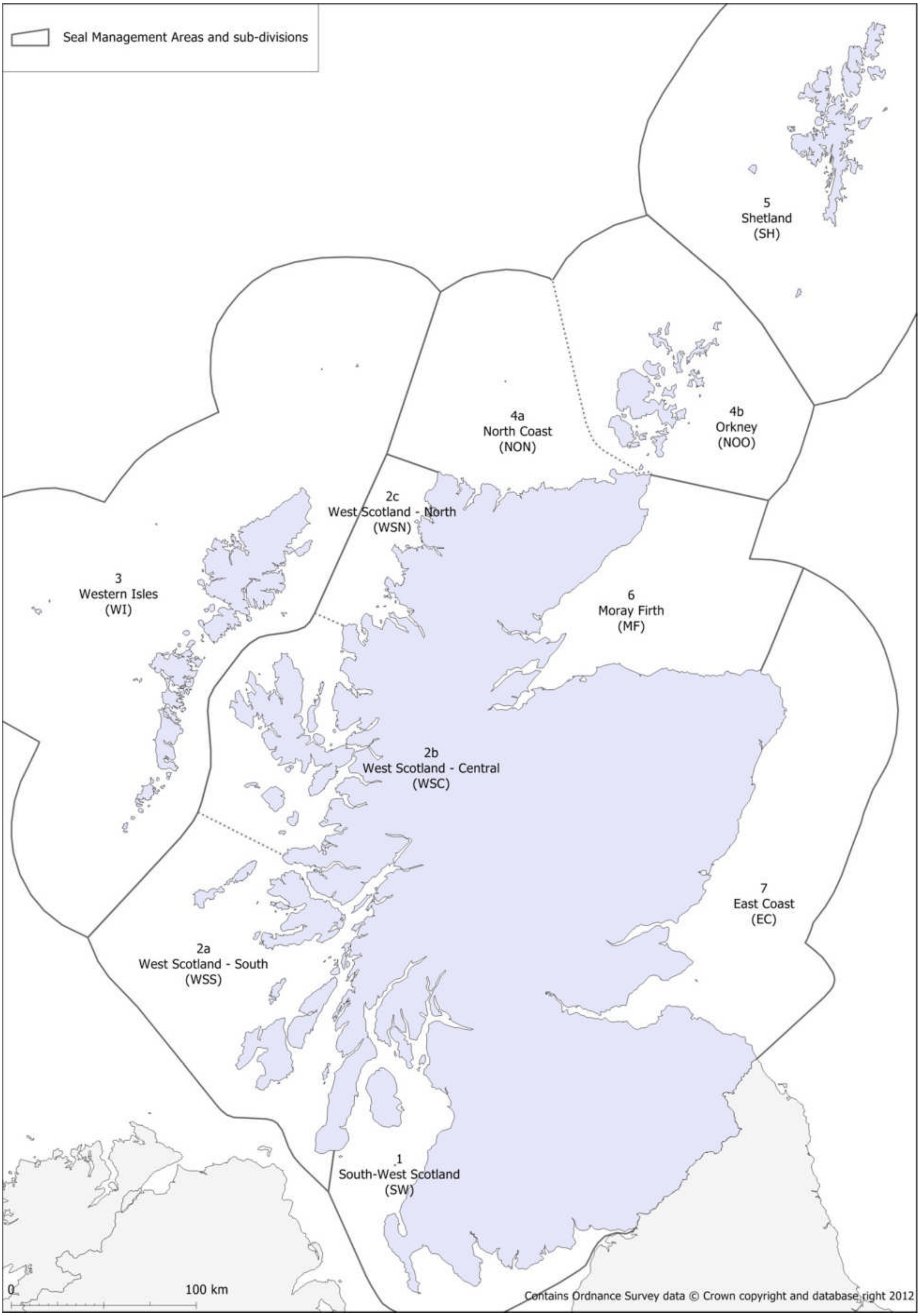

Figure 3. Seal Management Areas in Scotland. Dotted lines indicate sub-divisions.

Producing a list of 'Designated Seal Haul-out Sites'

Stage 1 - Identifying hotspots

First, a simplified coastline was generated from a high resolution *OS OpenData* mean low water shape file using *Manifold GIS*. Virtual Observation Points (VOPs) were placed at 100m intervals (or less for smaller islands and intertidal rocks) along the simplified coast, producing a total of 186,442 VOPs around Scotland (Figure 4).

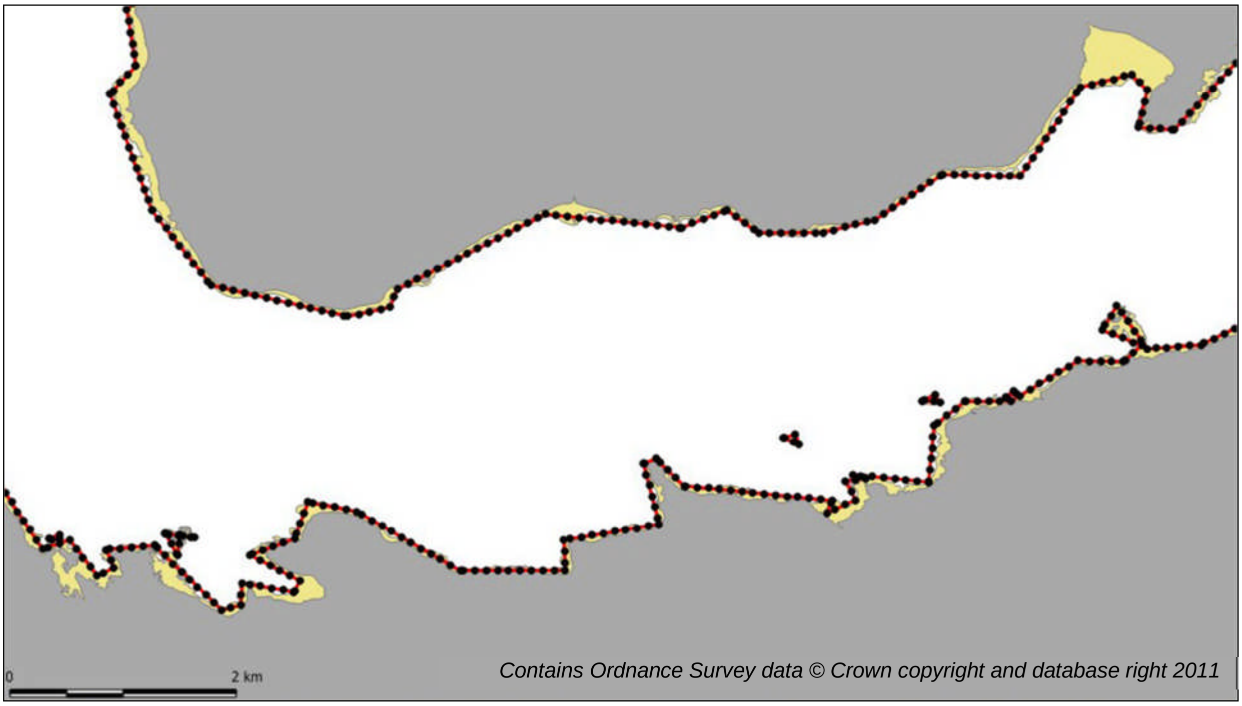

Figure 4. Virtual Observation Points (VOPs) every max 100m along a simplified low water coastline. Example shown is Loch Scridain, Mull.

The next step was to compile sighting histories of both species for each individual VOP. This was done within *Manifold GIS* by creating buffers with 300m radii around each VOP (Figure 5) and calculating – for each VOP – the sum of all sightings of each species that lie within the buffer boundary by year (1996-2010). This is equivalent to having an observer positioned at each VOP and recording all sightings within a 300m radius every time that part of the coast is surveyed (Table 3).

300m was chosen as an appropriate buffer radius for the following reasons:

- To ensure that all recorded seal sightings are contained within at least one buffer area. This is more or less the precision of the older data sets used (also taking into account that in some places the simplified coastline is further away from sighting locations than the actual coast).

- To a limited extent, this also helps deal with the fact that seals don't always haul out at exactly the same spot. So if, in one year, the same group of seals is recorded up to 600m further down the coast than in a previous year, both sightings will still lie within at least one individual buffer area.

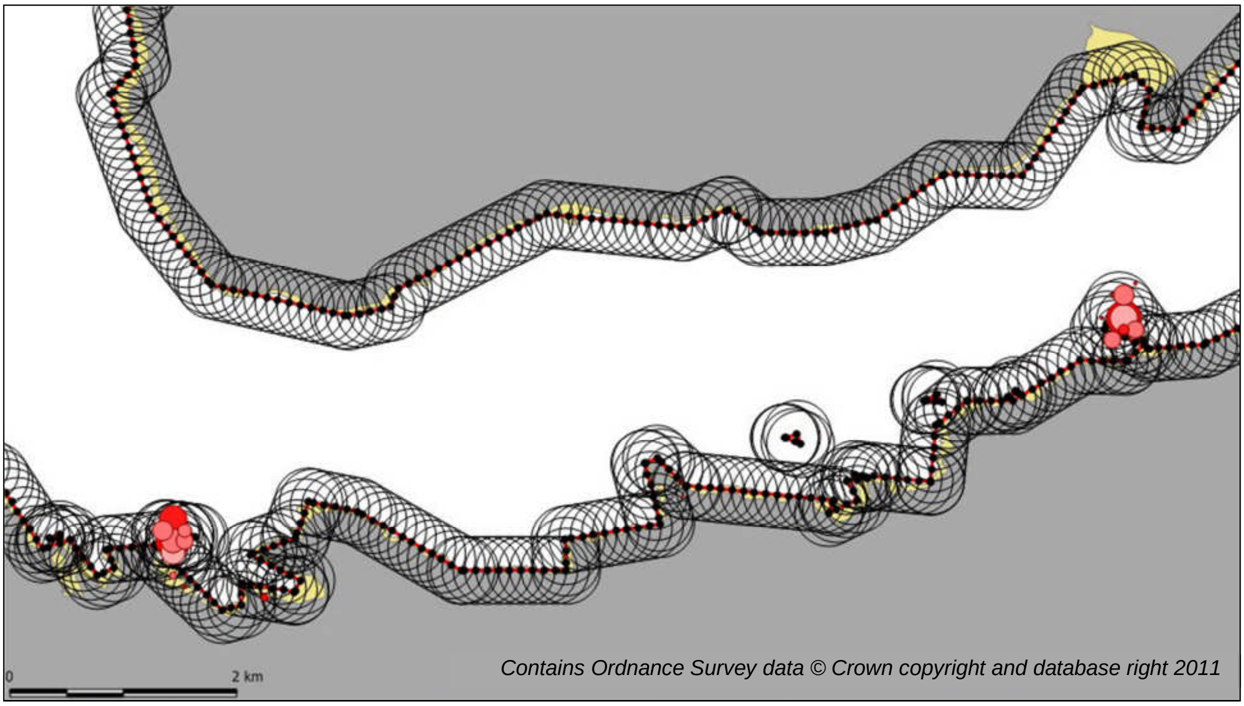

Figure 5. 300m buffer areas around every Virtual Observation Point (VOPs). Harbour seal sightings are also shown as filled red circles. Example shown is Loch Scridain, Mull.

Table 3. Example of possible sighting histories of harbour or grey seals for individual Virtual Observation Points (VOPs).

VOP	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
VOP-000001	0	n.s.	n.s.	n.s.	0	n.s.	n.s.	n.s.	n.s.	0	n.s.	n.s.	0	n.s.	n.s.
VOP-000002	52	n.s.	n.s.	n.s.	34	n.s.	n.s.	n.s.	n.s.	22	n.s.	n.s.	76	n.s.	n.s.
VOP-000003	52	n.s.	n.s.	n.s.	81	n.s.	n.s.	n.s.	n.s.	96	n.s.	n.s.	76	n.s.	n.s.
...															
VOP-186442	n.s.	13	n.s.	n.s.	n.s.	5	n.s.	n.s.	n.s.	n.s.	0	n.s.	10	14	5

n.s. = not surveyed

The individual sighting histories were then used to calculate a Time Weighted Average (TWA) of each species for each VOP using the following formula:

$$\mathrm{TWA} = \frac{\sum_{i=1996}^{2010} 0.8^{2010-Y_i} \cdot C_i}{\sum_{i=1996}^{2010} 0.8^{2010-Y_i}}$$

TWA : Time-Weighted Average

C_i : Count in Year i

Y_i : Year counted (1996-2010)

Using TWAs allowed us to place a greater emphasis on more recent counts without having to ignore several years' worth of data. This is a more robust approach compared to using only the most recent counts as it reduces the effect of natural variability and adding new data does not change the overall picture (e.g. the selection of key sites) as drastically. A high weighting factor is ideal for sites where seal numbers are very stable over the entire period but is not suitable to reflect genuine changes in haul-out use. It benefits sites where seal numbers have declined over time, whereas a low weighting factor benefits sites where seal numbers have increased over time. The weighting factor 0.8 (from the possible range 0.0 – 1.0) reduces the weight of a sighting by 20% for every one year step back in time (Figure 6). We believe that this makes sense for a data set ranging over 15 years because it supports sites where seals have declined without disadvantaging sites where seals have increased.

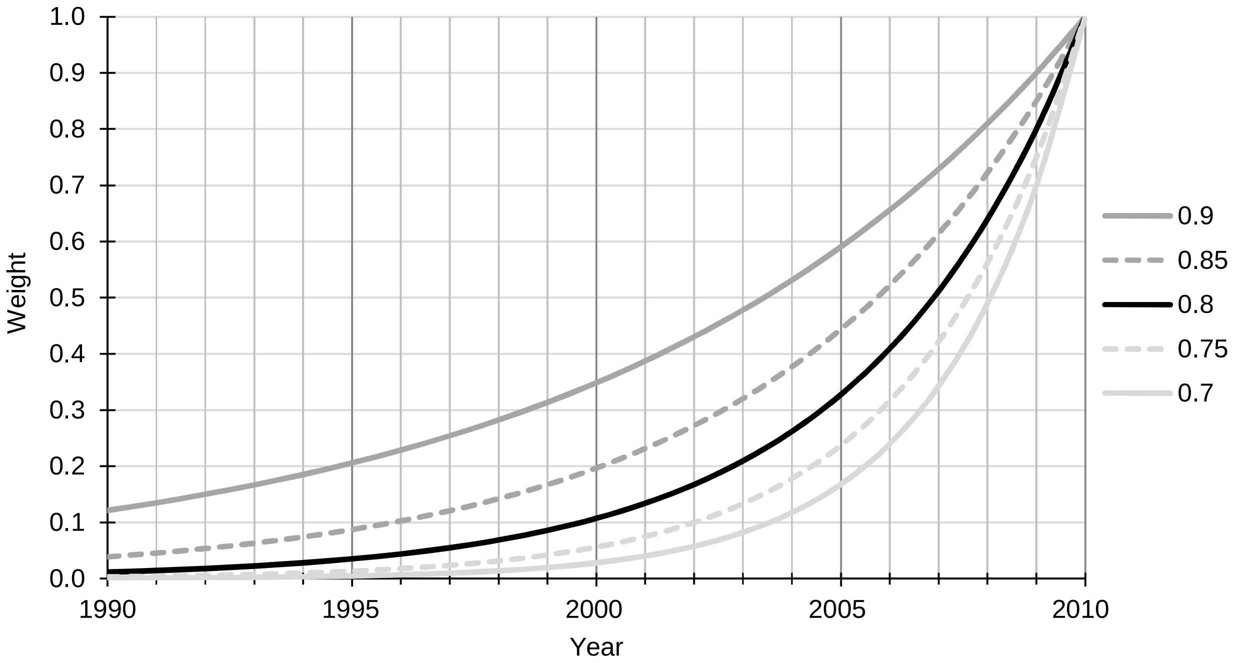

Figure 6. The influence of different weighting factors on the weight given to counts from 1990-2010.

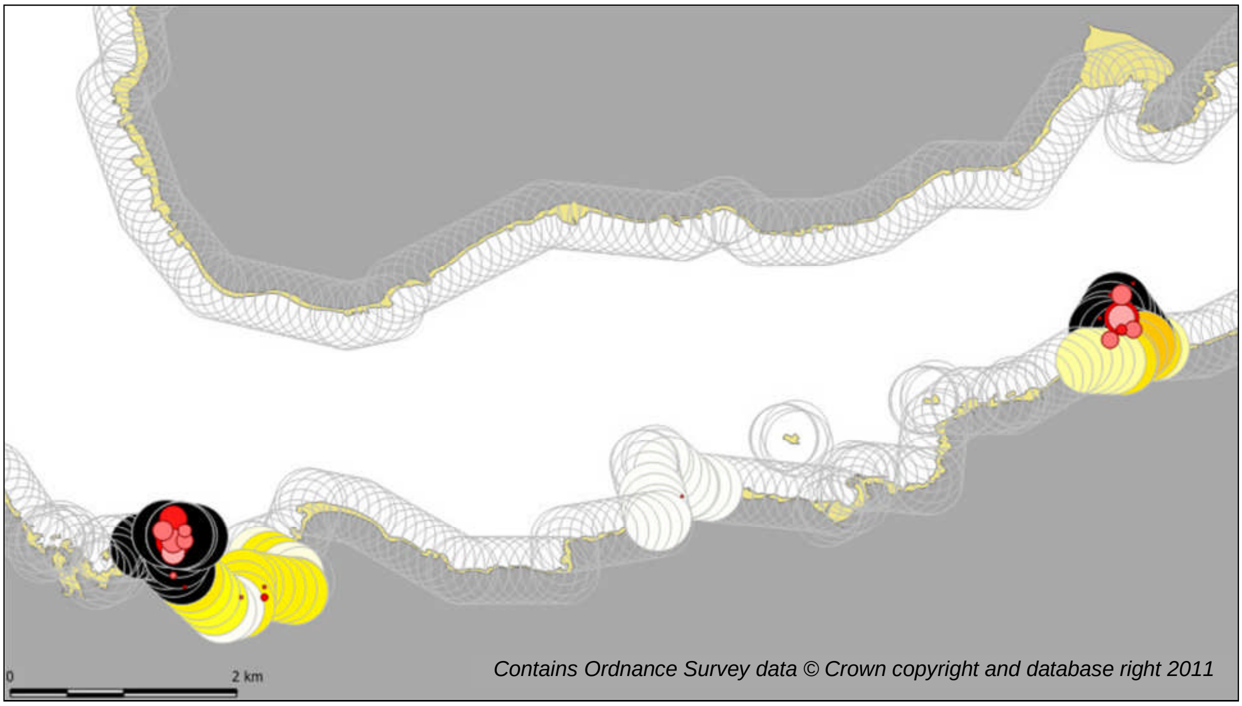

Figure 7. Virtual Observation Point buffers coloured by Time Weighted Average of harbour seal sightings 1996-2010 (yellow = low to black = high). Example shown is Loch Scridain, Mull.

Hotspots were then highlighted by colouring the VOPs according to their TWAs (Figure 7). This can be done in various ways. The aim is to study areas at a finer resolution in the order established by the TWA values. All areas with a TWA greater than 50 were examined first and site boundaries defined (see Stage 2), before moving to TWAs with values between 30-50, 20-30, 10-20 etc. This was continued until at least 50% of harbour seal and grey seal populations were covered in each Seal Management Area and sub-division by a combination of all 14 existing Special Areas of Conservation (SACs) for seals and the newly identified haul-out sites. This minimum figure was requested by Marine Scotland and Scottish Natural Heritage because it was considered to represent a good starting point in terms of achieving a balance between maximising seal protection while minimising potential implications for other sustainable activities around the coast. This minimum figure was increased for certain species in specific areas which showed a decline in numbers for that species (see Table 4 below). This was done to reflect the requirement for greater protection in such circumstances. The Seal Management Areas and sub-divisions are shown in Figure 3 and a list of all existing seal SACs is given in Appendix A.

Stage 2 - Defining individual haul-out sites

Site boundaries were defined by overlaying all available seal sighting data 1996-2010 onto detailed *OS OpenData* maps within *Manifold GIS* and drawing a polygon shape around parts of the coast, small islands and skerries that contained seal sightings (Figure 8A). This is a somewhat arbitrary process. It is not possible to be certain about where seals may or may not haul-out and it is therefore always possible for 'unimportant rocks' to be included and 'important rocks' to be excluded.
As described above for buffer areas, sighting histories and TWAs were calculated for each newly identified and defined site.
After the selection process was completed, as described in the next section, a GIS shapefile was created containing the detailed areas covered by each site (Figure 8B). This was done using Scotland mean high and low water shapefiles extracted from the *Digimap Ordnance Survey Collection* by Pope (2011).

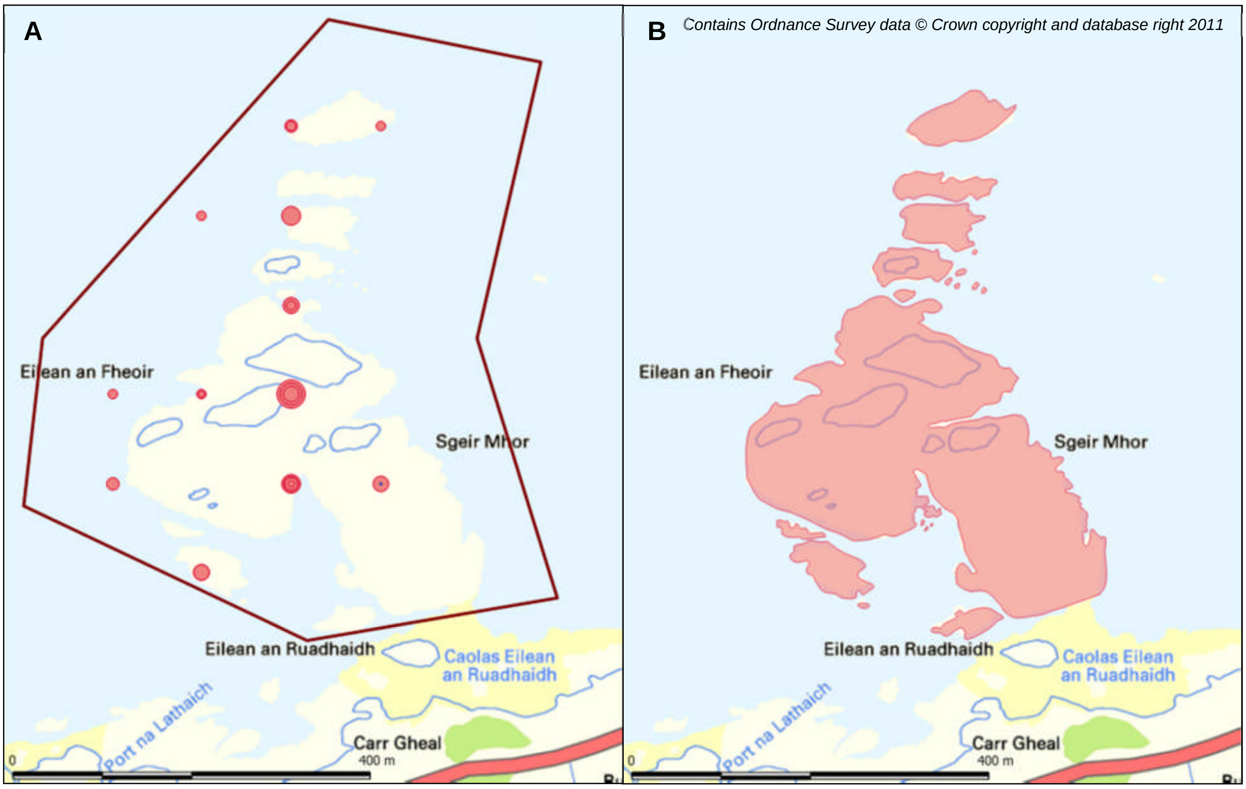

Figure 8. A Shows the Polygon used to calculate the sighting history for Eilean an Fheoir, a harbour seal haul-out site in Loch Scridain, Mull. **B** Shows the detailed area extracted from the *Digimap Ordnance Survey Collection* shapefiles.

Stage 3 - Selecting sites for designation

All identified sites were included in an *MS Excel 2010* database containing a harbour seal site list and a grey seal site list ranked by TWA, together with all associated information (e.g. Seal Management Area and sub-division, site name and location, TWAs for both species, grid references (of each site's centroid)). Sites shared by both species were included in both species' lists. A site was defined as being a shared site if both species contributed at least 10% to the total number of seals based on TWAs or if the site had been identified for both species independently as a haul-out site.

The final list of sites for designation was produced using the site selection criteria described below. This selection process was carried out for both species independently.

Selection criteria

1) Primary selection criterion:

   For each Seal Management Area and sub-division, a minimum population coverage target was set for each species, as given in Table 4. A minimum of at least 50% was set in all Seal Management Areas and sub-divisions where seal populations were either stable or increasing. A significantly larger proportion of the population was set for harbour seals in Seal Management Areas and sub-divisions where this species' populations have declined significantly and which feature seal conservation areas (http://www.scotland.gov.uk/Resource/Doc/295194/0112738.pdf).

   All seal SACs were included in the minimum coverage target so sites identified during the previous steps that lay within an SAC were excluded from this process. Starting with the site with the highest TWA in each Seal Management Area and sub-division, sites were added to the lists until the appropriate minimum population coverage was achieved for each species.

   For those Seal Management Areas and sub-divisions, where the target was set above the 50% cut-off used for stages 1 and 2, additional sites were identified where necessary in order to reach the higher target.

2) Secondary selection criteria:
   In addition to the sites selected by the primary selection criterion, all sites that contained a certain percentage of the Seal Management Area's TWA population were also added to the list:

   - for harbour seals: sites ≥ 5% of the Seal Management Area population

   - for grey seals: sites ≥ 10% of the Seal Management Area population

   These criteria were added to ensure the inclusion of any sites considered to be significant to that Seal Management Area's wider population.

Table 4. Selection criteria set for harbour and grey seals. A minimum of at least 50% of the local population of each seal species was set as the primary selection criteria. This was increased for harbour seals to 60% in the Western Isles and to 80% in all northern and eastern Seal Management Areas and sub-divisions where this species has been in decline in recent years.

Seal Management Area (SMA) or sub-division		Primary selection criteria: Minimum coverage targets		Secondary selection criteria: Site size relative to SMA's TWA	
		Harbour seals	Grey seals	Harbour seals	Grey seals
1	South-West Scotland	50%	50%	≥ 5%	≥ 10%
2a	West Scotland - South	50%	50%	≥ 5%	≥ 10%
2b	West Scotland - Central	50%	50%	≥ 5%	≥ 10%
2c	West Scotland - North	50%	50%	≥ 5%	≥ 10%
3	Western Isles	60%	50%	≥ 5%	≥ 10%
4a	North Coast	80%	50%	≥ 5%	≥ 10%
4b	Orkney	80%	50%	≥ 5%	≥ 10%
5	Shetland	80%	50%	≥ 5%	≥ 10%
6	Moray Firth	80%	50%	≥ 5%	≥ 10%
7	East Coast	80%	50%	≥ 5%	≥ 10%

This selection process produced a list containing a total of 150 seal haul-out sites (Appendix B). Table 5 shows in detail how many sites were selected and the criteria on which selection was based. Of these 150 sites, 116 sites were selected for the harbour seals only; 27 sites were selected for grey seals only, and 7 sites were selected for both species. Most sites (145) were selected under the primary selection criteria, only 5 sites were added under the secondary selection criteria. Note that a number of the 116 'harbour seal' sites and a number of the 27 'grey seal' sites were considered to contain sufficient numbers of the other species for them to be identified as shared sites in the final list. Figure 9 shows a map of Scotland with these 150 sites marked by purple circles. More detailed maps of all Seal Management Areas and sub-divisions are provided in Appendix D.

Table 5. The number of sites selected per Seal Management Area and sub-division based on the primary or secondary criteria for harbour and grey seals (excluding SACs). These sites are marked by purple circles in Figure 9.

	Seal Management Area (SMA) or sub-division	Sites selected based on: Primary selection criteria: Minimum coverage targets			Secondary selection criteria: Site size relative to SMA's TWA			
		Both	Harbour	Grey	Both	Harbour	Grey	Total sites
1	South-West Scotland	1	2	3	0	1	0	7
2a	West Scotland - South	0	12	3	0	0	0	15
2b	West Scotland - Central	1	4	5	0	0	0	10
2c	West Scotland - North	0	3	4	0	0	0	7
3	Western Isles	0	18	1	0	0	0	19
4a	North Coast	0	2	2	0	0	0	4
4b	Orkney	2	30	4	0	0	0	36
5	Shetland	3	36	4	0	0	0	43
6	Moray Firth	0	4	0	0	2	1	7
7	East Coast	0	1	0	0	1	0	2
	Total	7	112	26	0	4	1	150

Producing a list of additional 'Designated Seasonal Seal Haul-out Sites'

Compared to the process required to develop a list of year-round haul-out sites it was a much simpler task to produce a list of Designated Seasonal Seal Haul-out Sites to protect grey seal breeding colonies. All major grey seal colonies in Scotland are well-known and surveyed regularly to obtain pup production estimates.

It was decided to include all known grey seal breeding colonies in Scotland where at least 20 pups are born each year and which are not already covered by seal SACs or the list of designated haul-out sites (i.e. not all major grey seal breeding colonies are included in the seasonal seal haul-out site list because they were already on the designated seal haul-out site list).

There were 16 breeding colonies already covered by existing seal SACs, another 16 were covered by sites on the list of year-round haul-out sites. The above criteria identified a list of 45 additional grey seal breeding colonies for designation (Appendix C). Figure 9 shows a map of Scotland with these 45 seasonal sites marked by blue triangles. More detailed maps of all Seal Management Areas and sub-divisions are provided in Appendix D.

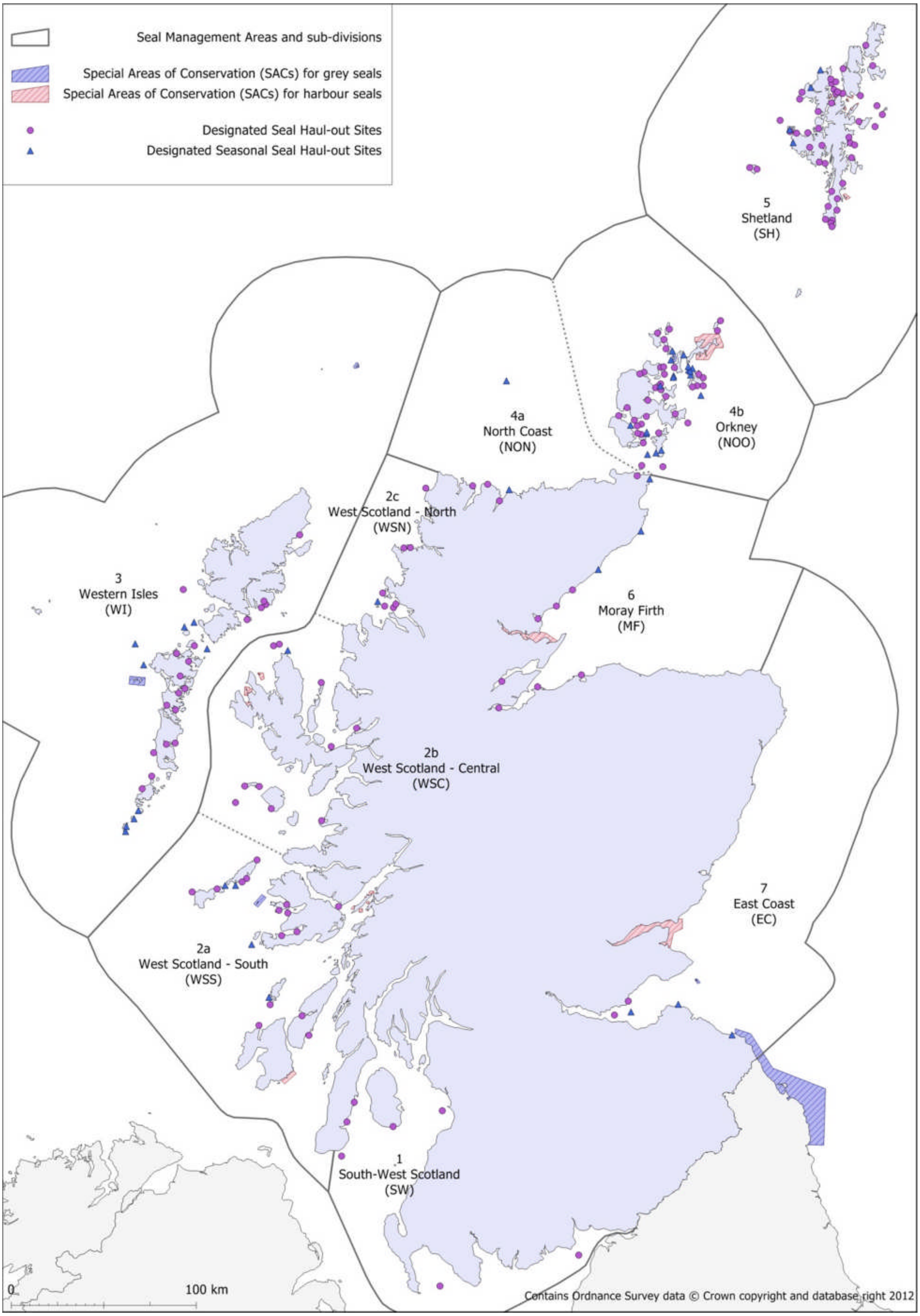

Figure 9. Map of Scotland indicating the location of proposed Designated Seal Haul-out Sites in Scotland. Year-round sites are marked by purple circles; seasonal sites (grey seal breeding colonies) are marked by blue triangles.

Limitations of data and methods used

Large datasets for both harbour and grey seals were available for designating seal haul-out sites but there remain large gaps in our knowledge waiting to be filled. Although, we believe the process described here is an appropriate way of selecting sites in a standardised manner, it is important to point out that a number of decisions had to be based on expert judgement using the best data available.
Some of the main issues to bear in mind are:

- The only extensive seal sighting dataset that covers the entire Scottish coast is exclusively from August surveys. This means that all year-round sites have been selected based on sightings and counts in August only. Seasonal variability is not taken into account although opportunistic data have shown that, at least in some places, there can be significant differences in the numbers of seals between seasons.

- The process used for selecting key seal haul-outs favours large sites over smaller sites. It assumes that the number of seals hauled out is a measure of the sites importance to the wider population. There may be other reasons that sites are important to seal populations but at present it is not possible to quantify these in any meaningful way and the list of designated sites has been produced with the only available metric.

- It was not possible to assess each seal haul-out site in a reliable and consistent manner to take into account the potential risk of harassment. This means that seals at some sites included in the lists may be unlikely to be subjected to activities that might cause harassment. This is considered a positive factor in the selection process since it means that significant seal haul-out sites are included whether or not they are potentially at risk or not. They are therefore protected against the possibility of future harassment.

- It would be interesting to compare the results using different buffer sizes (500m, 1km etc.) for the VOPs. The outcome is unlikely to be very different but larger buffer areas could potentially highlight additional sites where seals are dispersed in several smaller groups over larger areas or where the precise location is especially variable between surveys.

- The weighting factor of 0.8 used to calculate all the Time Weighted Averages (TWAs) is a value which we believe gives an appropriate relative weight to data collected over a 15 year period (see Figure 6).

- Seals are not aware of boundaries drawn on maps. In some cases it is easy to define the boundaries of a site, e.g. a small offshore island. In other cases it is very difficult to decide where one site ends and another site begins as seals can haul-out in slightly different places during different haul-out periods (depending on wind direction etc.). In high density areas it is also not straightforward to define separate sites. Using a standard minimum distance to distinguish between separate sites was not considered to be very useful. Therefore each site was studied and defined individually using our best judgement. Regardless of the method used, there is a great amount of variability in the size of individual sites.

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Appendix A – List of existing Special Areas of Conservation (SACs) for seals

	SAC Name	OSGB36 Easting[1]	OSGB36 Northing[1]	Species[2]	Pv% of SMA(sd)[3]	Hg% of SMA(sd)[3]
2a	**West Scotland - South**					
	South-east Islay Skerries	144632	647168	Pv	12%	0%
	Lismore	188899	747202	Pv	8%	0%
	Treshnish Isles	128889	743011	Hg	0%	3%
				Total:	**20%**	**4%**
2b	**West Scotland - Central**					
	Ascrib, Isay & Dunvegan	122143	856643	Pv	19%	9%
				Total:	**19%**	**9%**
3	**Western Isles**					
	Monach Islands	64000	862000	Hg	0%	42%
	North Rona	181062	1032560	Hg	0%	5%
				Total:	**0%**	**47%**
4b	**Orkney**					
	Sanday	371626	1043880	Pv	10%	4%
	Faray & Holm of Faray	352000	1036000	Hg	0%	6%
				Total:	**10%**	**10%**
5	**Shetland**					
	Mousa	446060	1124040	Pv	3%	4%
	Yell Sound	446744	1175499	Pv	6%	1%
				Total:	**10%**	**5%**
6	**Moray Firth**					
	Dornoch Firth & Morrich More	278434	885561	Pv	26%	52%
				Total:	**26%**	**52%**
7	**East Coast**					
	Firth of Tay & Eden Estuary	341990	729452	Pv	74%	72%
	Isle of May	366134	699417	Hg	0%	5%
	Berwickshire & North Northumberland Coast	416789	637166	Hg	0%	0%
				Total:	**74%**	**77%**

1 Grid references give a position lying within a SAC. Note that these point locations are not always very representative for areas extending over several (square) kilometres.

2 Pv: Harbour/common seal; Hg: Grey seal.

3 % of the Seal Management Area's (or sub-division's) Pv/Hg population attributed to the SAC calculated using Time Weighted Averages (TWA).
All percentages given are rounded to the nearest whole number. Therefore 0% does not neccessarily imply that no animals were counted.

Appendix B – List of 'Designated Seal Haul-out Sites'

Site-ID	Site Name	Location	OSGB36 Easting[1]	OSGB36 Northing[1]	Species[2]	Pv% of SMA(sd)[3]	Hg% of SMA(sd)[3]
1	**South-West Scotland**						
SW-001	Sanda & Sheep Island	Mull of Kintyre	173000	604800	Pv&Hg	31%	20%
SW-002	Sound of Pladda Skerries	S Arran	201000	620800	Pv&Hg	14%	4%
SW-003	Rubha nan Sgarbh	Kilbrannan Sound, E Kintyre	179900	634000	Pv	11%	0%
SW-004	Yellow Rock	Ardnacross Bay, E Kintyre	176000	623200	Pv	9%	0%
SW-005	Lady Isle	Firth of Clyde, W of Troon	227500	629300	Pv&Hg	2%	8%
SW-006	Little Scares	Luce Bay, between Mull of Galloway and Burrow Head	226350	534500	Hg	0%	14%
SW-007	Solway Firth Outer Sandbank	Solway Firth, between Southerness Pt and Dubmill Pt	301300	551100	Hg	0%	12%
					SAC(s):	0%	0%
					Total:	**66%**	**59%**
2a	**West Scotland - South**						
WSS-001	Cairns of Coll	NE Coll	127400	765000	Pv&Hg	4%	2%
WSS-002	Craighouse Small Isles & Lowlandman's Bay	E Jura	155500	670000	Pv	3%	0%
WSS-003	Loch na Corrobha Skerries	Ross of Mull	140600	724100	Pv	3%	0%
WSS-004	South Ulva Islands & Little Colonsay	S Ulva	139100	737800	Pv	3%	0%
WSS-005	East End of Sound of Mull	Sound of Mull	171400	740000	Pv	3%	0%
WSS-006	Laggan Bay (Mull)	NE of Ulva	143400	740900	Pv	3%	0%
WSS-007	Eilean an Fheoir	Ross of Mull	149000	726100	Pv	2%	0%
WSS-008	Arinthluic	E Coll	121800	755100	Pv	2%	0%
WSS-009	Vaul & Salum Bays	NE Tiree	105800	749400	Pv	2%	0%
WSS-010	Outer Loch Tarbert	Loch Tarbert, W Jura	151600	680600	Pv	2%	0%
WSS-011	Friesland Bay	E Coll	119200	753200	Pv	2%	0%
WSS-012	Inch Kenneth & Geasgills	Loch na Keal, W Mull	144000	736300	Pv	2%	0%
WSS-013	S Oronsay	S Oronsay	134500	686700	Hg	0%	22%
WSS-014	Hough Skerries	NW Tiree	92200	747900	Hg	0%	19%
WSS-015	Nave Island	NW Islay	128400	675400	Hg	0%	13%
					SAC(s):	20%	4%
					Total:	**51%**	**61%**
2b	**West Scotland - Central**						
WSC-001	Arisaig	Arisaig	162300	786300	Pv	10%	0%
WSC-002	Pabay & Ardnish Peninsula	SE Skye	167400	826300	Pv	7%	1%
WSC-003	Loch a' Bhraige	N Rona, Sound of Raasay	162100	861000	Pv	5%	0%
WSC-004	Kishorn Island & Strome Islands	Loch Carron	181100	836400	Pv	5%	0%
WSC-005	Hyskeir	SW of Canna	115600	796100	Pv&Hg	4%	13%
WSC-006	W Canna	W Canna	120600	804900	Pv&Hg	1%	13%
WSC-007	Sgeir a' Phuirt	outside Canna Harbour, E Canna	128500	804700	Pv&Hg	0%	5%
WSC-008	Fladda-chuain	off N Skye	136300	881000	Pv&Hg	0%	6%
WSC-009	SW Rum	SW Rum	135100	792700	Hg	0%	5%
WSC-010	Sgeir nam Maol	E of Fladda-chuain, off N Skye	139300	881800	Hg	0%	4%
					SAC(s):	19%	9%
					Total:	**51%**	**55%**
2c	**West Scotland - North**						
WSN-001	Sgeirean Glasa	Summer Isles	196400	902500	Pv	20%	1%
WSN-002	Rubha Creag Iomhair	Eddrachillis Bay	210200	934100	Pv	15%	0%
WSN-003	Carn nan Sgeir	Summer Isles	201200	901700	Pv	15%	1%
WSN-004	Eilean Chrona	Clashnessie Bay, N of Lochinver	206800	933900	Hg	0%	21%
WSN-005	Glas-Leac Mor (Summer Isles)	NW Summer Isles	195400	909600	Hg	0%	11%
WSN-006	Am Balg	W of Sandwood Bay, S of Cape Wrath	218600	966200	Hg	0%	11%
WSN-007	Iolla Mhor	S of Horse Island, E Summer Isles	202400	903600	Hg	0%	9%
					SAC(s):	0%	0%
					Total:	**50%**	**54%**
3	**Western Isles**						
WI-001	Inner Loch Maddy	Loch Maddy	90400	872500	Pv	8%	0%
WI-002	Oronsay (N Uist)	N North Uist, S of Boreray	84000	876900	Pv	7%	0%
WI-003	Inner Loch Eynort	E South Uist	78300	827700	Pv	6%	0%
WI-004	Sgeir Leathann (Broad Bay)	Broad Bay, NE of Stornoway, NE Lewis	150500	940900	Pv&Hg	6%	2%
WI-005	Inner Bagh nam Faoileann & Loch Chill Eireabhaigh	Bagh nam Faoileann, SE Benbecula	83200	846400	Pv	4%	0%
WI-006	Fiaray	Sound of Barra, N of Barra	70300	810300	Pv&Hg	4%	2%
WI-007	Loch Langais	Loch Eport	85800	864600	Pv	3%	0%
WI-008	Gairbh-Eilean Ronaigh	E of Grimsay, SE North Uist	88200	857700	Pv	3%	0%
WI-009	Luib Bhan	SW Benbecula	78400	848900	Pv	3%	0%
WI-010	Loch a' Bhaigh	E Berneray, Sound of Harris	93400	881000	Pv	3%	0%
WI-011	Flodda	NE Benbecula	84900	855400	Pv	3%	0%
WI-012	Aird Ghrein & Sgeir Liath	NW Barra	65200	803600	Pv&Hg	2%	1%
WI-013	Aird Dhubh	Loch Bhrolluim, SE Lewis	132200	903200	Pv	2%	0%
WI-014	Rubha Bholuim	N of Loch Eynort, E South Uist	83100	828200	Pv	2%	0%
WI-015	Askernish Skerries South	SW South Uist	71500	823000	Pv&Hg	2%	1%
WI-016	An Acarsaid a Deas	SW Scalpay, E Harris	121900	895100	Pv	1%	0%
WI-017	Bhalamus	Loch Bhalamuis, SE Lewis	129600	901700	Pv	1%	0%
WI-018	Eilean Glas Cheann Chrionaig	Loch Bhrolluim, SE Lewis	131000	905150	Pv	1%	0%
WI-019	Gasker	W of Harris	87500	911500	Hg	0%	4%
					SAC(s):	0%	47%
					Total:	**61%**	**58%**

(continued)

Site-ID	Site Name	Location	OSGB36 Easting[1]	OSGB36 Northing[1]	Species[2]	Pv% of SMA(sd)[3]	Hg% of SMA(sd)[3]
4a	**North Coast**						
NON-001	Gills Bay	W of Duncansby Head	333000	972900	Pv&Hg	65%	17%
NON-002	Kyle of Tongue Sandbanks	Kyle of Tongue	258400	959500	Pv&Hg	19%	2%
NON-003	Eilean Hoan	Loch Eriboll mouth	244000	967500	Pv&Hg	7%	18%
NON-004	Loch Eriboll & Whiten Head	E of Whiten Head, E of Loch Eriboll	252000	968400	Hg	1%	48%
					SAC(s):	0%	0%
					Total:	**92%**	**84%**
4b	**Orkney**						
NOO-001	Eynhallow & Westside	between Mainland & Rousay	336600	1029100	Pv&Hg	7%	1%
NOO-002	South North Ronaldsay	S North Ronaldsay	376400	1051500	Pv&Hg	6%	2%
NOO-003	Switha	E of Hoy	336200	990800	Pv&Hg	5%	1%
NOO-004	Skerry of Wastbist	S Westray	348400	1041700	Pv&Hg	4%	1%
NOO-005	Deer Sound	E Mainland	353400	1006500	Pv&Hg	4%	1%
NOO-006	Selwick	N Hoy	323000	1005600	Pv&Hg	4%	1%
NOO-007	Holm of Papa Westray & North Wick	E Papa Westray	350400	1052400	Pv&Hg	4%	3%
NOO-008	Odness	E Stronsay	368600	1026200	Pv&Hg	3%	1%
NOO-009	Bay of Ireland	SW Mainland	327500	1009900	Pv	3%	0%
NOO-010	Bay of Holland E & Tor Ness	S Stronsay	365400	1021800	Pv&Hg	2%	3%
NOO-011	Barrel of Butter	W Scapa Flow	335200	1000900	Pv	2%	0%
NOO-012	Damsay & Holm of Grimbister	Mainland central	338700	1013900	Pv&Hg	2%	0%
NOO-013	Holm of Houton	S Mainland, Bring Deeps	331400	1003100	Pv&Hg	2%	0%
NOO-014	Cava	W Scapa Flow	332900	999900	Pv	2%	0%
NOO-015	Helliar Holm North & Elwick	S Shapinsay	348600	1015900	Pv	2%	0%
NOO-016	Costa & Burgar	N Mainland, opp. from Eynhallow	334300	1028200	Pv&Hg	2%	0%
NOO-017	Flotta Oil Terminal	N Flotta	335100	995400	Pv	2%	0%
NOO-018	Seal Skerry (Eday)	SW Eday	353000	1031500	Pv&Hg	1%	0%
NOO-019	Taing Skerry & Grass Holm	Wide Firth, W of Shapinsay	345900	1019700	Pv&Hg	1%	0%
NOO-020	Ve Ness	S Mainland, Scapa Flow	337900	1005100	Pv&Hg	1%	0%
NOO-021	NW Water Sound	W Burra	344500	996100	Pv	1%	0%
NOO-022	Holm of Rendall	E of Rendall, N Mainland	342900	1020700	Pv&Hg	1%	0%
NOO-023	Narr Ness	Rack Wick, NW Westray	343900	1050200	Pv&Hg	1%	1%
NOO-024	North end Mill Bay	E Stronsay	366200	1028100	Pv&Hg	1%	2%
NOO-025	Spo Ness to Ness of Brough	N Westray	347400	1046800	Pv&Hg	1%	0%
NOO-026	Bay of Houseby	SE Stronsay	368700	1021800	Pv&Hg	1%	1%
NOO-027	Sweyn Holm	NE of Gairsay	345500	1022900	Pv&Hg	1%	0%
NOO-028	Holm of Scockness	between Rousay & Egilsay	345600	1031700	Pv	1%	0%
NOO-029	Egilsay North	Egilsay, E of Rousay	347300	1032000	Pv&Hg	1%	1%
NOO-030	Stroma	Stroma, Pentland Firth	335500	978500	Pv&Hg	1%	9%
NOO-031	SE Egilsay	SE Egilsay	347700	1028100	Pv&Hg	1%	0%
NOO-032	N & E Fara	E of Hoy, Scapa Flow	333200	996000	Pv&Hg	1%	1%
NOO-033	Pentland Skerries	Pentland Firth E	346800	977950	Hg	0%	17%
NOO-034	Greenli Ness	SE Rothiesholm, SW Stronsay	362800	1021200	Hg	0%	5%
NOO-035	Seal Skerry (N Ronaldsay)	N Dennis Ness, NE North Ronaldsay	378100	1056800	Hg	0%	4%
NOO-036	Copinsay	E of SE Mainland	360400	1001600	Hg	0%	3%
					SAC(s):	10%	10%
					Total:	**81%**	**69%**
5	**Shetland**						
SH-001	E South Shetland	S Mainland E, N of Sandwick	444200	1131300	Pv	13%	1%
SH-002	West Linga & Lunning Sound Holms	E Mainland, Lunning Sound	452800	1164800	Pv	4%	1%
SH-003	Ve Skerries	NW of Papa Stour	410300	1165500	Pv&Hg	4%	15%
SH-004	Effirth Voe & Bixter Voe	Bixter Voe	432800	1151800	Pv	3%	0%
SH-005	Sanda & Score Islands	The Deeps, SW Mainland	434600	1142100	Pv	3%	0%
SH-006	Ungam	Sullom Voe	438100	1174700	Pv	2%	0%
SH-007	Lamba	Yell Sound S	439300	1182000	Pv	2%	0%
SH-008	Little Roe	Yell Sound S	440400	1179800	Pv	2%	1%
SH-009	Sligga Skerry & North End of Bigga	S Yell Sound, NW of Bigga	444050	1180000	Pv&Hg	2%	1%
SH-010	Isle of West Burrafirth & Tainga Skerries	S St Magnus Bay	425200	1158650	Pv&Hg	2%	1%
SH-011	Channer Wick & Hos Wick	Hoswick, SE Mainland	441200	1122900	Pv	2%	0%
SH-012	Scudills Wick	E Mainland, South Nesting Bay	447400	1156300	Pv	2%	0%
SH-013	Egilsay, Heodale & Isle of Gunnister	E St Magnus Bay	430900	1170100	Pv	2%	0%
SH-014	Rumble, East Linga, Grif Skerry	East of Whalsay	461500	1162100	Pv&Hg	2%	2%
SH-015	Uyea Sound	E Vementry	431000	1161000	Pv	2%	0%
SH-016	Colsay & Bay of Scousburgh	SW Mainland	436300	1118750	Pv&Hg	2%	1%
SH-017	Gruting Voe NW Head	Gruting Voe, SW Shetland	426200	1150800	Pv&Hg	1%	1%
SH-018	Fetlar NW Islands	NW of Fetlar	460300	1195000	Pv&Hg	1%	4%
SH-019	Skea Skerries (Yell Sound)	E North Roe, Yell Sound	438000	1185400	Pv	1%	0%
SH-020	Point of Bugarth	W Yell	444400	1193200	Pv&Hg	1%	0%
SH-021	Isle of Stenness	Esha Ness, NW Mainland	420800	1176800	Pv&Hg	1%	2%
SH-022	Tinga Skerry	Yell Sound, between Brother Isle and Little Roe	441500	1180800	Pv&Hg	1%	1%
SH-023	Swarta Skerry & Mo Geo	SW Papa Stour	415600	1159300	Pv&Hg	1%	1%
SH-024	Aa Skerry	Roe Ness, The Deeps, SW Mainland	431400	1142750	Pv&Hg	1%	0%
SH-025	Da Smell Geo	E Foula	397800	1139100	Pv&Hg	1%	2%
SH-026	Eswick Holm	South Nesting, E Mainland	448300	1153100	Pv	1%	0%
SH-027	Westing	SW Unst	456500	1205900	Pv	1%	0%
SH-028	Little Holm	Yell Sound	440400	1186200	Pv&Hg	1%	0%
SH-029	Hoo Stack	off Eswick (South Nesting)	450500	1152000	Pv&Hg	1%	0%
SH-030	Tros Wick	E South Mainland	441000	1116700	Pv	1%	0%

(continued)

Site-ID	Site Name	Location	OSGB36 Easting[1]	OSGB36 Northing[1]	Species[2]	Pv% of SMA(sd)[3]	Hg% of SMA(sd)[3]
SH-031	Ure	N Esha Ness	422100	1180600	Pv	1%	0%
SH-032	Head of Calsta	S of Burra Voe, Yell Sound	437750	1187550	Pv	1%	0%
SH-033	Holm of Melby	Sound of Papa	419200	1158500	Pv	1%	0%
SH-034	Skerries of Neapaback	off SE Yell	453650	1178600	Pv&Hg	1%	0%
SH-035	Muckle Skerry (Out Skerries)	NW Out Skerries	462700	1173400	Pv&Hg	1%	2%
SH-036	Holm of Beosetter	N of Bressay	449000	1145200	Pv&Hg	1%	1%
SH-037	Maywick	South West Mainland	438150	1127050	Pv&Hg	1%	0%
SH-038	Toab & Scatness	W of Sumburgh	438500	1111400	Pv&Hg	1%	0%
SH-039	Lady's Holm	S tip Mainland	437700	1109700	Pv&Hg	1%	8%
SH-040	The Guens, Filla & The Benelips	Out Skerries S, NE of Whalsay	465600	1168600	Pv&Hg	0%	3%
SH-041	Foula West	Foula West	393800	1139900	Hg	0%	7%
SH-042	Horse Island	S tip Mainland	438400	1107750	Hg	0%	6%
SH-043	Siggar Ness	S Fitful Head, S tip Mainland	434800	1111700	Hg	0%	5%
					SAC(s):	10%	5%
					Total:	**80%**	**72%**
6	**Moray Firth**						
MF-001	Ardersier	W of Nairn	279100	858800	Pv&Hg	22%	7%
MF-002	Beauly	Beauly Firth	258000	847400	Pv	18%	0%
MF-003	Findhorn	Findhorn, W of Elgin	302800	865200	Pv&Hg	10%	4%
MF-004	Loch Fleet	Loch Fleet	279200	895700	Pv	9%	0%
MF-005	Cromarty Firth	Cromarty Firth	259700	861700	Pv	9%	0%
MF-006	Brora	Brora, NE of Loch Fleet	289300	902500	Pv&Hg	8%	2%
MF-007	Lothmore	between Helmsdale and Brora	298000	911200	Pv&Hg	4%	13%
					SAC(s):	26%	52%
					Total:	**106%**	**78%**
7	**East Coast**						
EC-001	Kinghorn Rocks	Firth of Forth N	328100	688600	Pv&Hg	11%	2%
EC-002	Inchmickery and Cow & Calves	Firth of Forth	320600	681100	Pv&Hg	7%	1%
					SAC(s):	74%	77%
					Total:	**92%**	**79%**

1 Grid references give a position lying within a site's area. Note that these point locations are not always very representative for sites extending over several (square) kilometres.

2 Pv: Harbour/common seal; Hg: Grey seal.
If a site was identified for both species independantly or both species contribute at least 10% to the total number of seals within the site, the site is regarded to be a shared site (Pv&Hg).

3 % of the Seal Management Area's (or sub-division's) Pv/Hg population attributed to the site calculated using Time Weighted Averages (TWA). For some sites more counts (i.e. years) are available for calculating the TWA than are available for calculating the TWA of the entire Seal Management Area or sub-division. This means that the sum of all sites does not add up to 100% and can be smaller as well as greater (see Moray Firth).
All percentages given are rounded to the nearest whole number. Therefore 0% does not neccessarily imply that no animals were counted.

Appendix C – List of 'Designated Seasonal Seal Haul-out Sites'

Colony-ID	Colony Name	Location	OSGB36 Easting[1]	OSGB36 Northing[1]	Pup production[2]
2a	**West Scotland - South**				
BC-001	Gunna	between Coll and Tiree	110100	751300	500+
BC-002	Oronsay Strand	W Oronsay	133800	690700	50+
BC-003	Soa (Mull)	SW of Iona	124400	719300	50+
BC-004	Soa (Coll)	S Coll	115600	751300	20+
2b	**West Scotland - Central**				
BC-005	Trodday	off N tip of Skye	144000	878600	50+
2c	**West Scotland - North**				
BC-006	Glas-Leac Beag	Summer Isles	192600	904900	50+
3	**Western Isles**				
BC-007	Shillay (SoH)	NW Sound of Harris	88100	891200	250+
BC-008	Pabbay	E Pabbay, SW of Barra	60800	787300	250+
BC-009	Sound of Harris Islands	E Sound of Harris	100400	879400	250+
BC-010	Berneray	N Berneray, SW of Barra	56200	780500	250+
BC-011	Mingulay	E Mingulay, SW of Barra	56600	783200	200+
BC-012	Coppay	N Sound of Harris	93300	893800	50+
BC-013	Sandray	NW Sandray, SW of Barra	63100	791700	20+
BC-014	Haskeir	12km off NW North Uist	61500	882000	20+
BC-015	Causamul	W of W North Uist	66100	870700	20+
4a	**North Coast**				
BC-016	Eilean nan Ron (Tongue)	off Kyle of Tongue	263600	965400	100+
BC-017	Sule Skerry	60km N of Kyle of Tongue	262200	1024500	20+
4b	**Orkney**				
BC-018	Linga Holm	W of Stronsay	361800	1027500	4,000+
BC-019	Swona	SW of South Ronaldsay	338600	984500	1,500+
BC-020	Holm of Huip	N of Stronsay	362900	1031200	1,000+
BC-021	Muckle Green Holm	SW of Eday	352600	1027100	500+
BC-022	Calf of Eday	NE of Eday	358000	1038500	500+
BC-023	N Flotta	NE Flotta, Scapa Flow	337900	995700	500+
BC-024	Little Linga	NW of Stronsay	360700	1030300	500+
BC-025	Sty Taing	Links Ness, NW Stronsay	361500	1029700	250+
BC-026	Holms of Spurness	Spur Ness, SW Sanday	360500	1032100	250+
BC-027	South Ronaldsay W	SW South Ronaldsay	343000	985400	250+
BC-028	Gairsay	off Mainland, E of Tingwall	345300	1021700	200+
BC-029	Calf of Flotta	off NE Flotta, Scapa Flow	338100	996700	200+
BC-030	Little Green Holm	SW of Eday	352500	1026300	150+
BC-031	Auskerry	S of Stronsay	367400	1016500	150+
BC-032	South Ronaldsay E	SE South Ronaldsay	346000	986800	150+
BC-033	Rusk Holm	W of Eday	351300	1035800	100+
BC-034	S Westray	SE Westray	352000	1040500	100+
BC-035	NE Hoy	NE Hoy	329300	1000300	100+

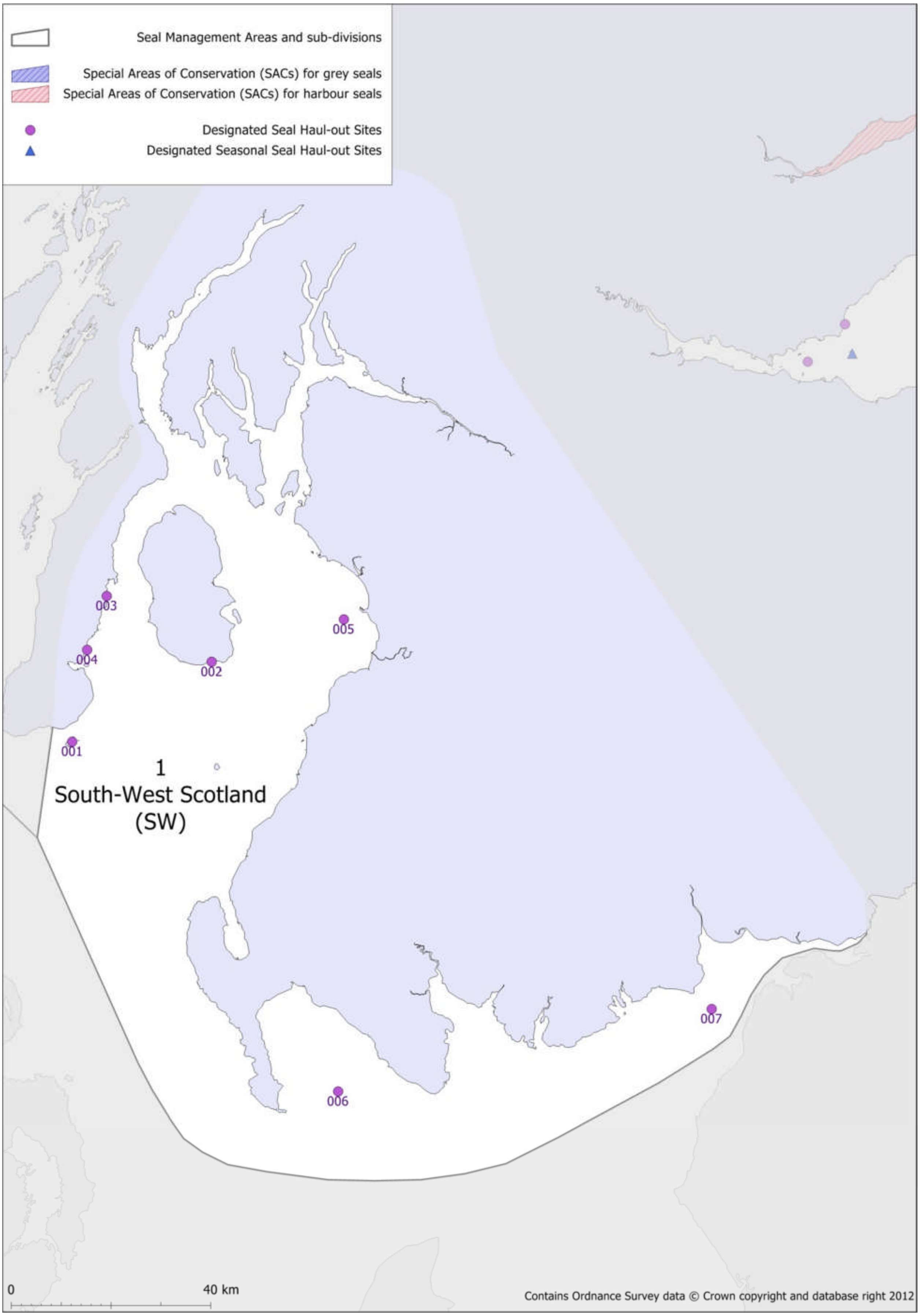
(continued)

Colony-ID	Colony Name	Location	OSGB36 Easting[1]	OSGB36 Northing[1]	Pup production[2]
5	**Shetland**				
BC-036	Uyea	NW North Roe	432000	1192600	200+
BC-037	Papa Stour	off Sandness (W Mainland)	415500	1160500	50+
BC-038	Ronas Voe	NW Mainland	426800	1183000	50+
BC-039	Dale	SW of Sandness (W Mainland)	417200	1153300	20+
6	**Moray Firth**				
BC-040	Dunbeath-Helmsdale	SW of Wick	312000	922200	500+
BC-041	Duncansby Head	N of Wick	339800	971200	250+
BC-042	Wick-Lybster	SW of Wick	334900	942900	100+
7	**East Coast**				
BC-043	Fast Castle	between Dunbar and Eyemouth	384200	670300	1,500+
BC-044	Inchkeith	halfway between Kinghorn and Leith	329500	682700	250+
BC-045	Craigleith	off North Berwick	355200	687000	50+

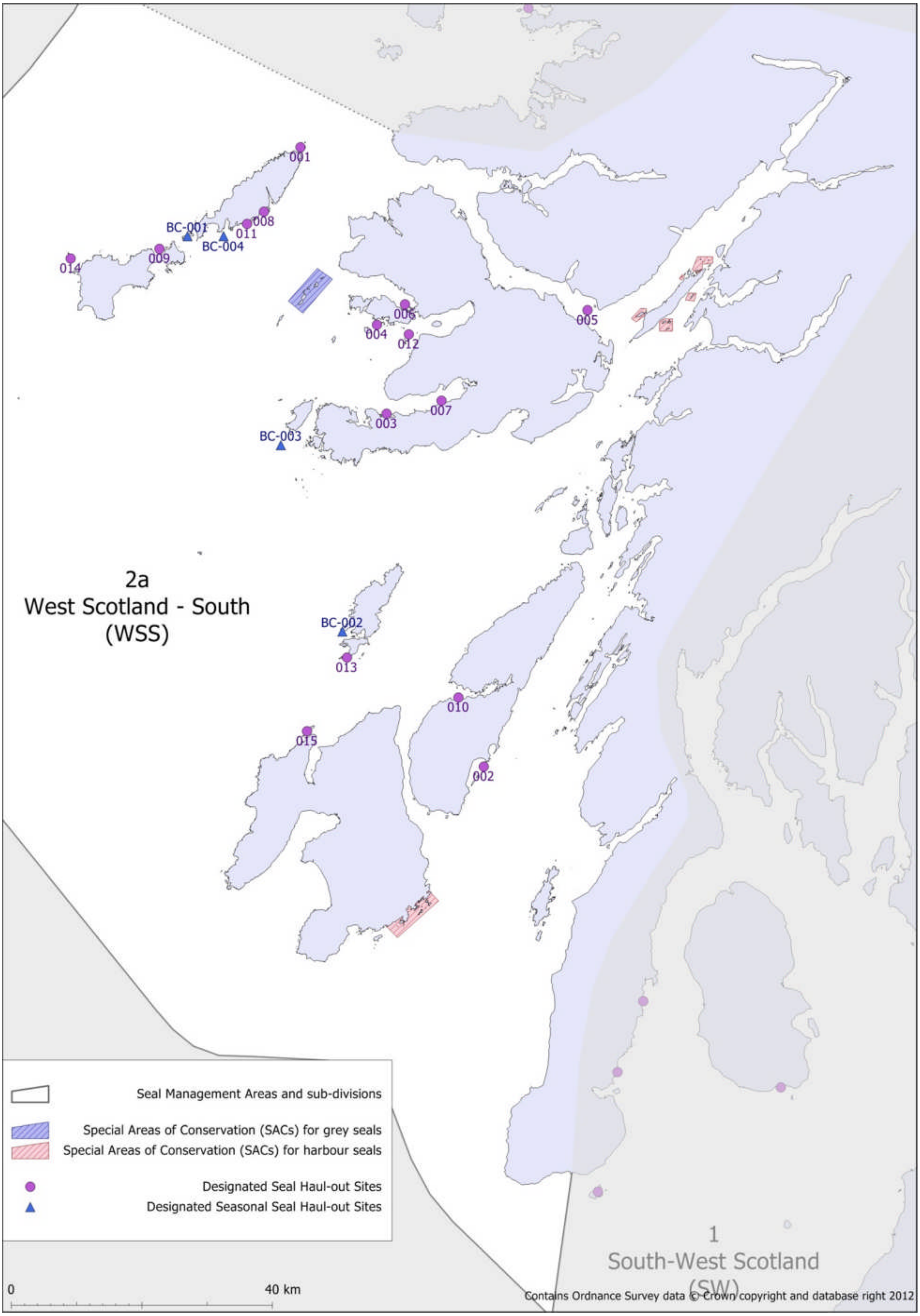
1 Grid references give a position lying within a site's area. Note that these point locations are not always very representative for sites extending over several (square) kilometres.

2 Using most recent grey seal pup production estimate available.

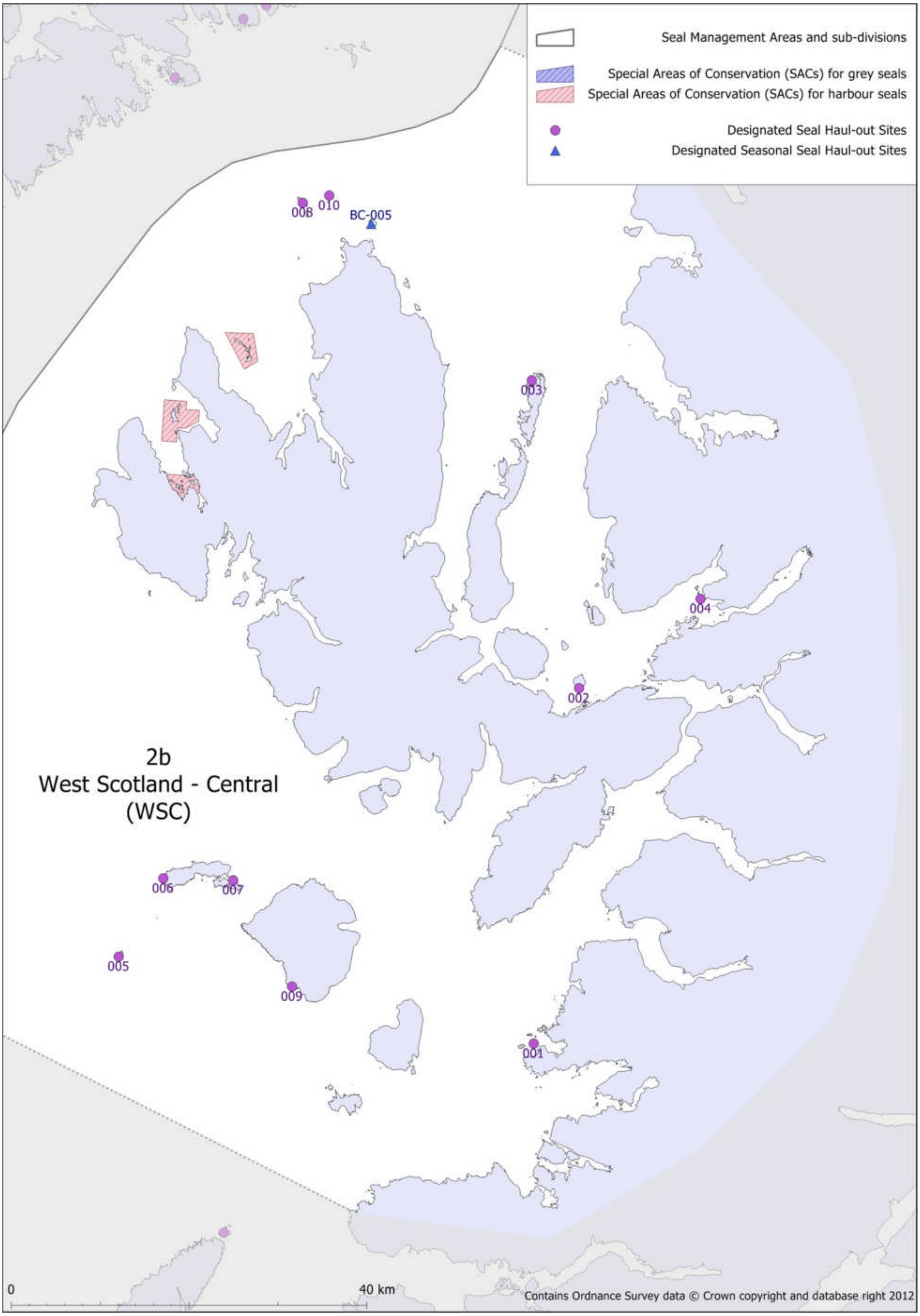
Appendix D – Maps of Seal Management Areas and sub-divisions showing sites



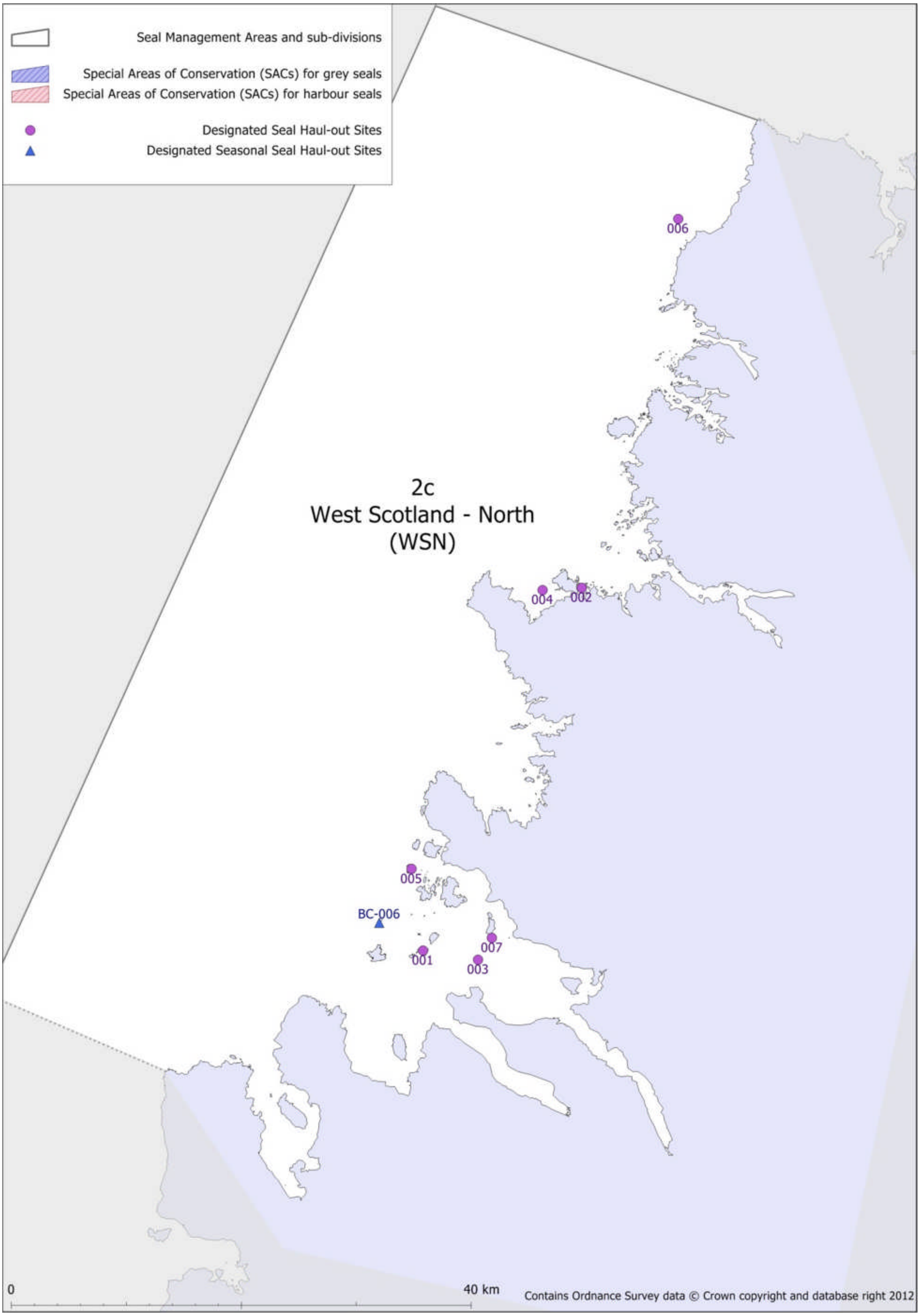
1 South-West Scotland: Proposed Designated Seal Haul-out Sites are marked by purple circles (SWS-001 to 007). Note that these point locations are not always very representative of sites that cover several (square) kilometres.



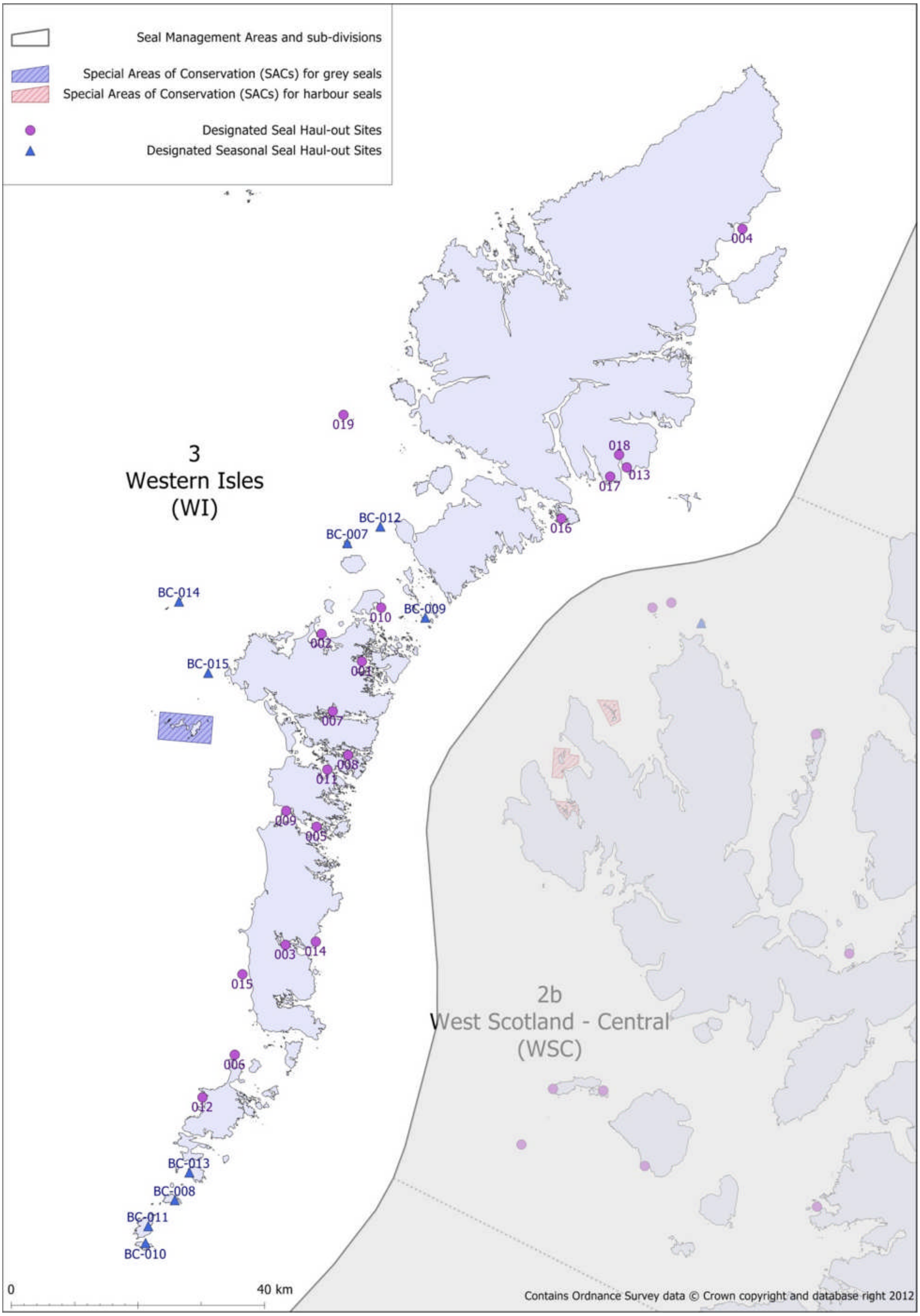
2a West Scotland - South: Proposed Designated Seal Haul-out Sites are marked by purple circles (WSS-001 to 015); proposed Designated Seasonal Seal Haul-out Sites are marked by blue triangles (BC-001 to 004). Note that these point locations are not always very representative of sites that cover several (square) kilometres.



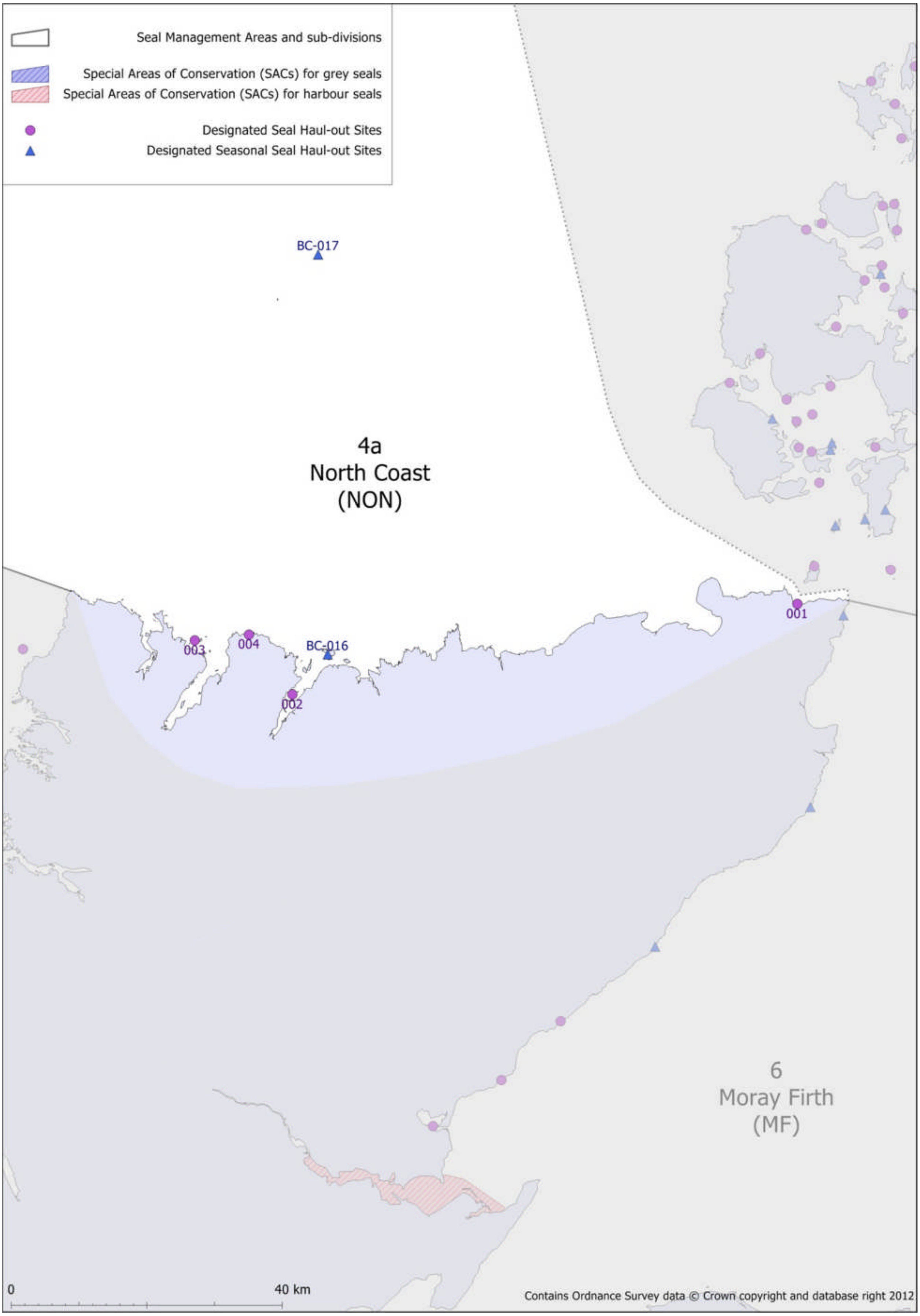
2b West Scotland - Central: Proposed Designated Seal Haul-out Sites are marked by purple circles (WSC-001 to 010); proposed Designated Seasonal Seal Haul-out Sites are marked by blue triangles (BC-005).
Note that these point locations are not always very representative of sites that cover several (square) kilometres.



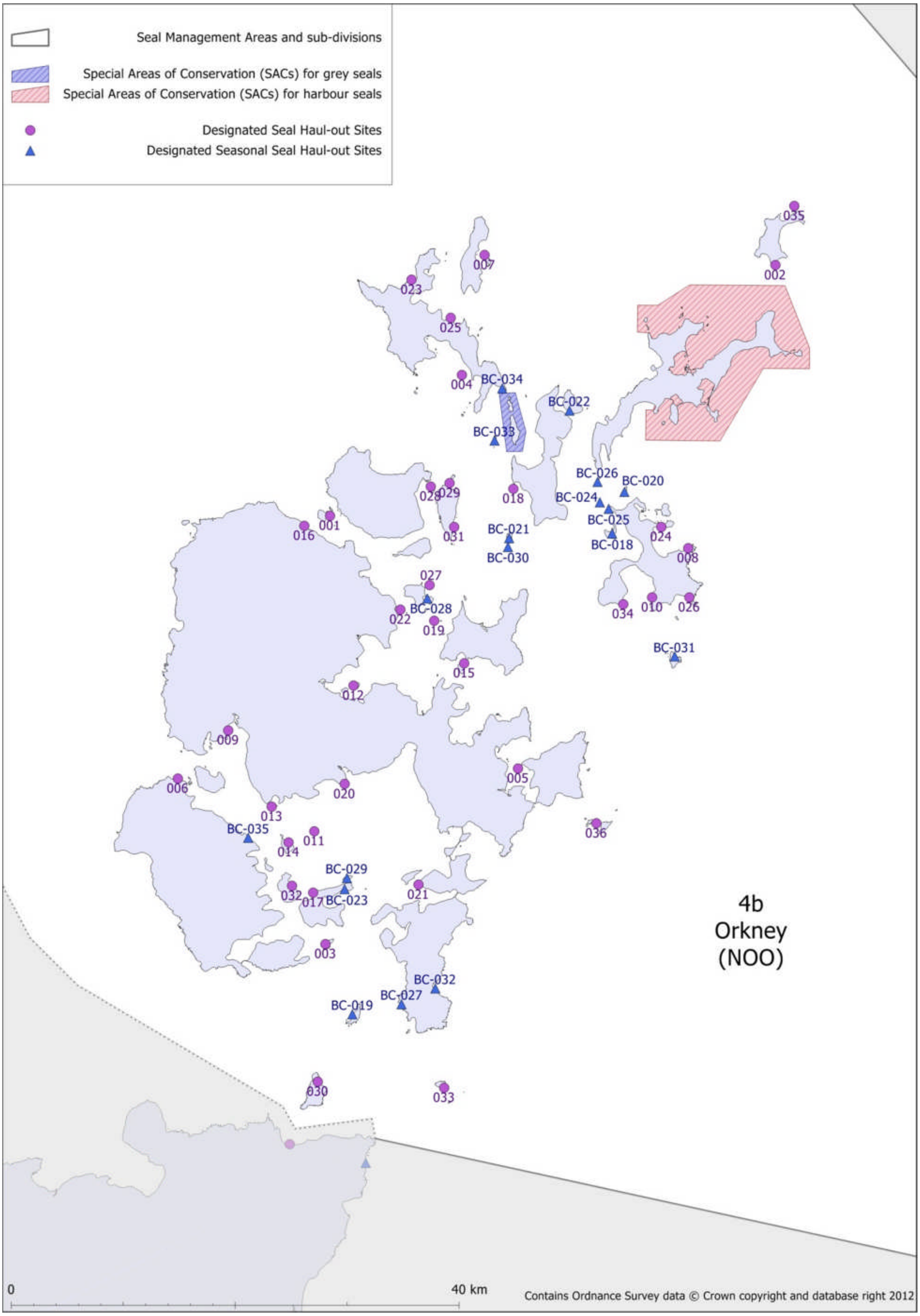
2c West Scotland - North: Proposed Designated Seal Haul-out Sites are marked by purple circles (WSN-001 to 007); proposed Designated Seasonal Seal Haul-out Sites are marked by blue triangles (BC-006).
Note that these point locations are not always very representative of sites that cover several (square) kilometres.



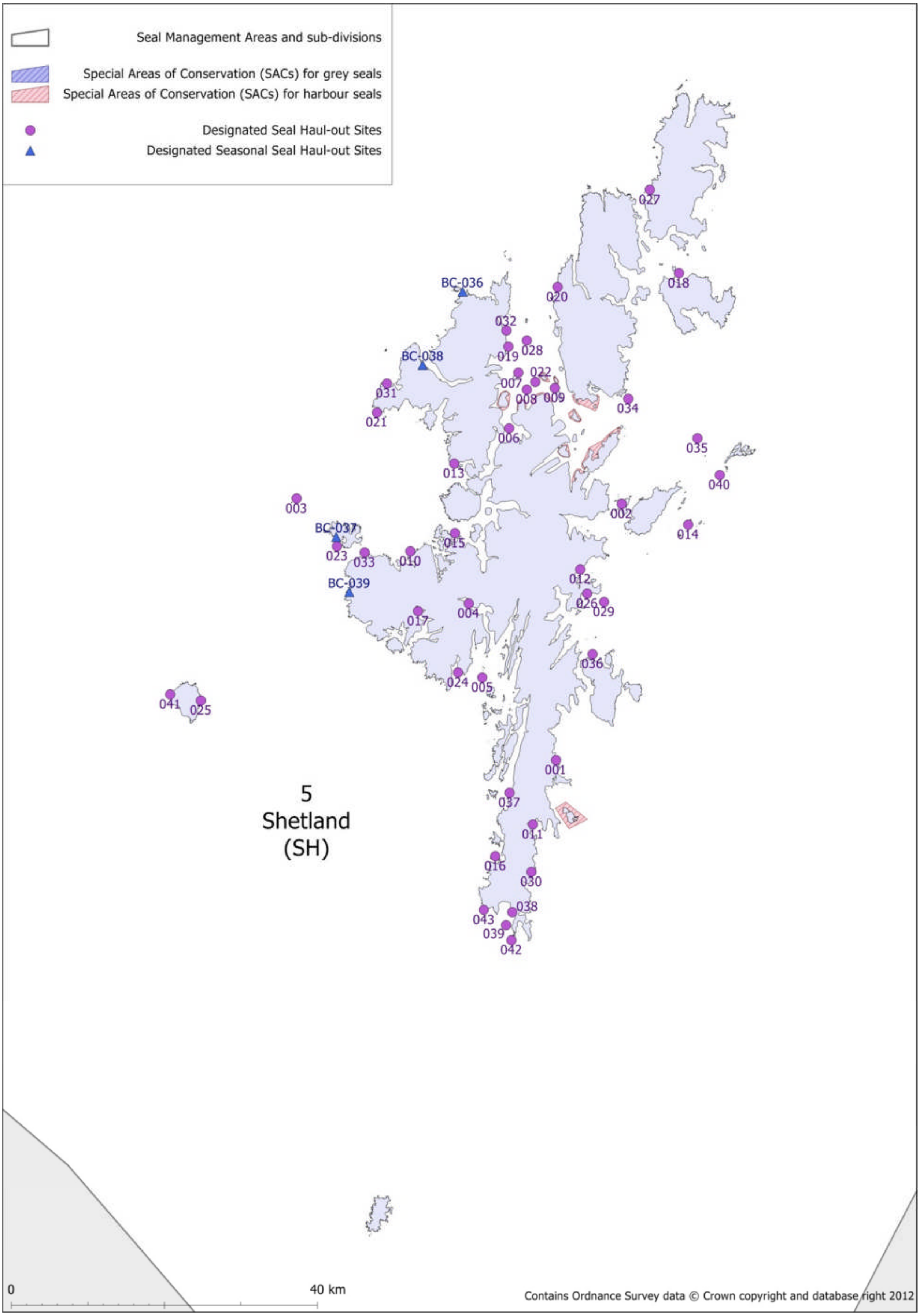
3 Western Isles: Proposed Designated Seal Haul-out Sites are marked by purple circles (WI-001 to 019); proposed Designated Seasonal Seal Haul-out Sites are marked by blue triangles (BC-007 to 015).
Note that these point locations are not always very representative of sites that cover several (square) kilometres.



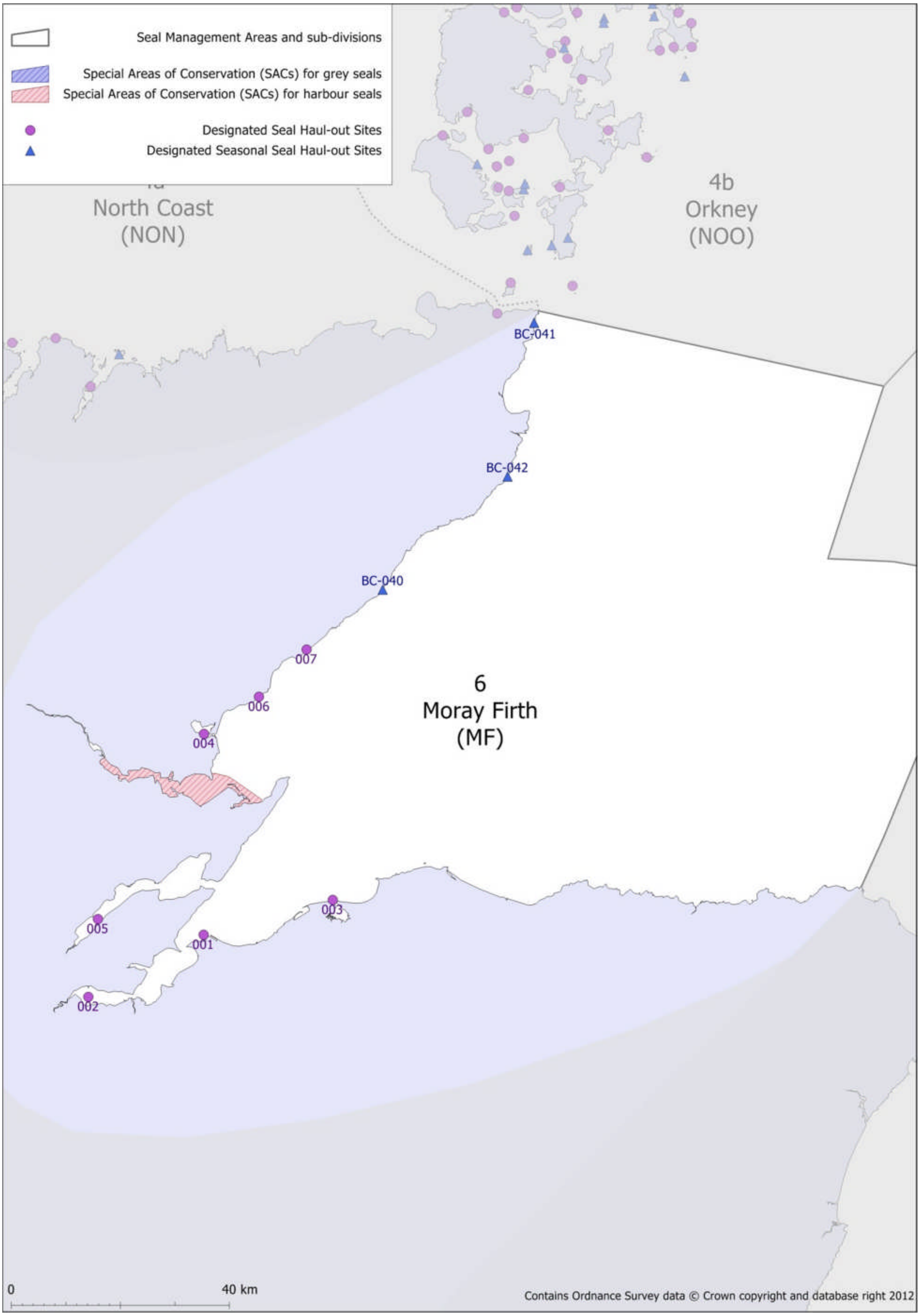
4a North Coast: Proposed Designated Seal Haul-out Sites are marked by purple circles (NON-001 to 004); proposed Designated Seasonal Seal Haul-out Sites are marked by blue triangles (BC-016 to 017).
Note that these point locations are not always very representative of sites that cover several (square) kilometres.



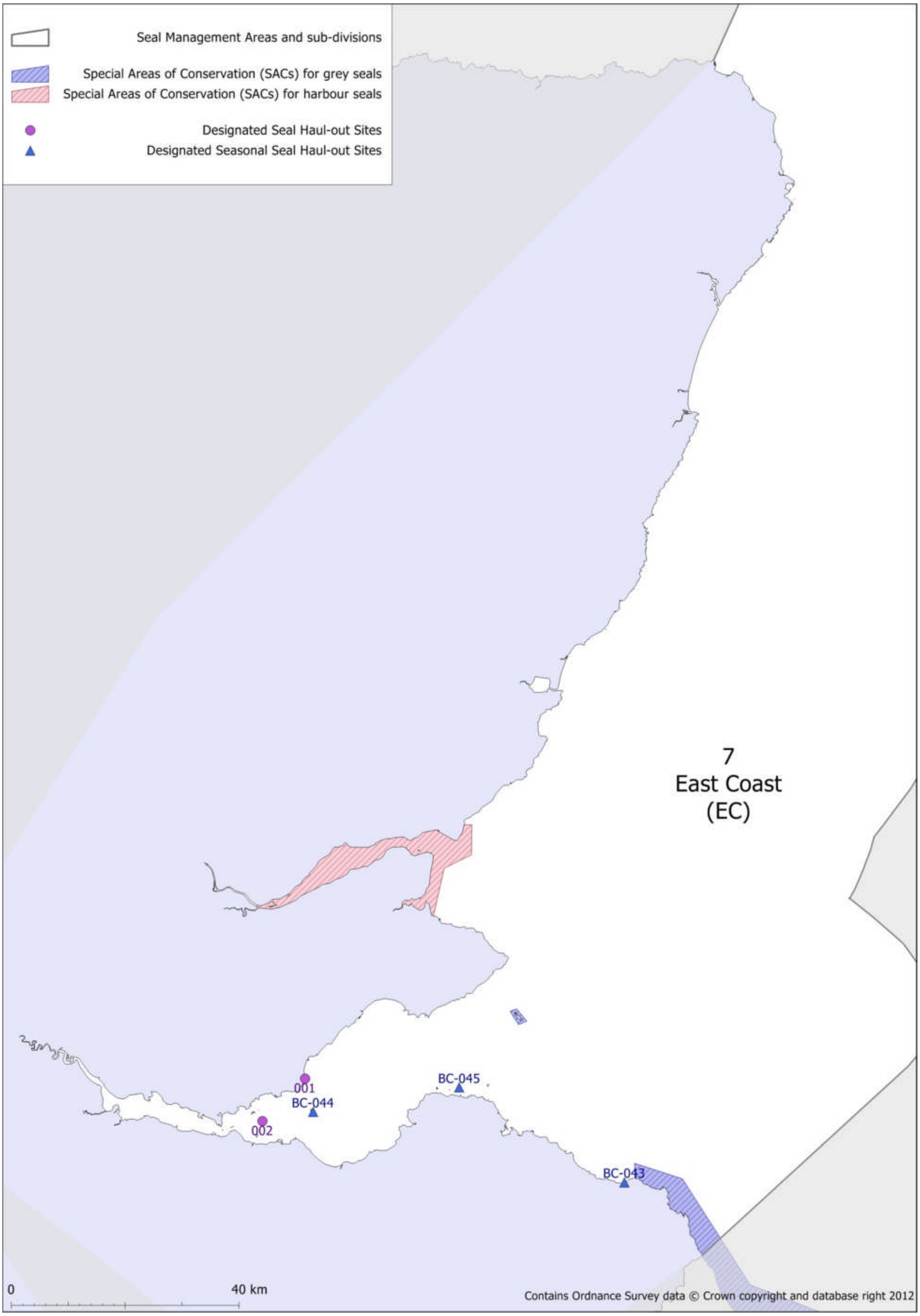
4b Orkney: Proposed Designated Seal Haul-out Sites are marked by purple circles (NOO-001 to 036); proposed Designated Seasonal Seal Haul-out Sites are marked by blue triangles (BC-018 to 035).
Note that these point locations are not always very representative of sites that cover several (square) kilometres.



5 Shetland: Proposed Designated Seal Haul-out Sites are marked by purple circles (SH-001 to 043); proposed Designated Seasonal Seal Haul-out Sites are marked by blue triangles (BC-036 to 039).
Note that these point locations are not always very representative of sites that cover several (square) kilometres.



6 Moray Firth: Proposed Designated Seal Haul-out Sites are marked by purple circles (MF-001 to 007); proposed Designated Seasonal Seal Haul-out Sites are marked by blue triangles (BC-040 to 042).
Note that these point locations are not always very representative of sites that cover several (square) kilometres.



7 East Coast: Proposed Designated Seal Haul-out Sites are marked by purple circles (EC-001 to 002); proposed Designated Seasonal Seal Haul-out Sites are marked by blue triangles (BC-043 to 045).
Note that these point locations are not always very representative of sites that cover several (square) kilometres.

Appendix E – SMRU aerial survey methods

The Sea Mammal Research Unit (SMRU) at the Scottish Oceans Institute, University of St Andrews, carries out surveys of harbour seals and grey seals to contribute to the Natural Environment Research Council's (NERC) statutory obligations under the Marine (Scotland) Act 2010 and the Conservation of Seals Act 1970 to provide 'scientific advice on matter relating to the management of seal populations' to the UK government. An essential component of this advice is information on the size and distribution of seal populations around the UK, particularly in Scotland where over 85% of both species of UK seals are found. The annually submitted advice can be found on SMRU's website (link to SCOS Reports, see page 77 in the 2009 document).

SMRU harbour seal moult surveys

Helicopter surveys

This method is generally applied to survey parts of the Scottish coast each year and produces a complete estimate for the whole of Scotland approximately every five years.

During the harbour seal moult in August, helicopter surveys are carried out using a thermal imager which is sensitive to infrared radiation in the 8 - 14 µm wavebands and is equipped with a dual telescope (x2.5 and x9 magnification). The imager is mounted on a pan-and-tilt head and operated out of the helicopter window.

When surveying, the helicopter follows the contours of the coast operating at a height of 150-250 m and a distance of 300-500 m offshore to ensure that seals are not disturbed. A digital video camcorder, attached to the imager, provides a real colour image to match the thermal image. Both images are displayed continuously on a monitor placed in front of the camera operator and simultaneously recorded to a digital video recorder. Seals are detected and counted on the monitor using the thermal image. For each sighting the location, time, species and number of seals are recorded directly onto Ordnance Survey 1:50 000 maps. Since 2006, most groups of seals are also photographed using a digital SLR camera equipped with an image-stabilised 70-300mm lens.

In general, differentiating between harbour and grey seals using a thermal image is possible on account of their different thermal profile, size and head-shape. When hauled out, their group structure also differs. Grey seals form tight and disorganised aggregations close to the water while harbour seals have greater inter-individual distances and are often a bit further from the water's edge. Species identification in the field is aided by the 'real' camcorder image and by direct observation using binoculars. Species identity and the number of seals in groups are later confirmed by reviewing both the digital thermal video and the digital still images.

To maximise numbers counted, surveys are carried out no more than two hours before or after the local low tide times occurring between approximately 12:00 and 17:30hrs local time. To further reduce the effects of environmental variables on number of seals counted, surveys are not carried out on rainy days. The thermal imager cannot 'see' through heavy rain and seals often abandon their haul-out sites and return to the water in medium to heavy prolonged rain.

Fixed-wing surveys

Certain areas on the east coast of Scotland (mainly the Moray Firth but also the Tay and Eden estuaries) are surveyed almost annually using fixed-wing aircraft, if not covered by the helicopter survey. The major seal haul-out sites in these areas are well known. They are often situated on sandbanks making it easier to spot seals without the help of a thermal imager. All groups of seals are photographed through the aircraft's side windows using a handheld digital SLR camera and recorded onto paper maps.

As described above for helicopter surveys these fixed-wing surveys are only carried out within certain tidal windows and in suitable weather conditions.

SMRU grey seal pup surveys

Grey seals return each year to traditional colonies to breed. Not only do females return to the same location within a colony, but they regularly return to the colony at which they were born. The timing of breeding varies around the Scottish coast. The earliest colonies are in the Inner Hebrides, followed by the Outer Hebrides, Shetland and Orkney. Latest of all are the colonies in the Firth of Forth. In each area, breeding occurs over approximately two months, with individual pups remaining on their breeding colony for approximately five weeks before departing to sea. A series of up to five aerial surveys are flown over the main breeding colonies by fixed-wing aircraft, at intervals of 10 to 13 days (weather permitting). Pups are counted from high resolution vertical aerial images and we use a maximum likelihood model to estimate the total number of pups born at each colony from the series of counts. Annual surveys were carried out up to 2010.

Appendix F – Manifold GIS actions

Creating a simplified coastline

1) Open layer containing detailed coastline.
2) Under 'Drawing' menu select: 'Simplify'
3) In the 'Simplify' pop-up window enter the Distance: 100 Meters and unselect 'Remove small branches'.

Creating VOPs along a simplified coastline

1) Open layer containing simplified coastline.
2) Under 'Drawing' menu select: 'Segmentize'
3) In the 'Segmentize' pop-up window enter the Distance: 100 Meters
4) In the Transform toolbar select the operator 'Points' and click Apply.

Creating a buffer around each VOP

1) Select the layer containing the points.
2) In the Transform toolbar select the operator 'Buffers', enter the radius (300) in the argument box and click Apply.
   The argument box uses the same units of measure as the drawing (in this case: meters).

Sum all sightings of a given species that lie within the boundary of each buffer

1) Under 'Drawing' menu select: 'Spatial Overlay'
2) In the 'Spatial Overlay' pop-up window select the Source: *Layer containing Seal Sightings*, and the Target: *Layer containing Buffer Areas*. Select Method: Points to containing areas.

Wilson, L.J. and Hammond, P.S.

The diet of harbour and grey seals around Scotland: update on progress

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

Summary

In 2010, a project funded by the Scottish Government was initiated to provide a comprehensive assessment of regional and seasonal variation in harbour seal diet composition and prey consumption through the analysis of prey remains (fish otoliths and cephalopod beaks) recovered from scats collected from haul-out sites throughout Scotland. The project also includes estimation of the diet of grey seals in key regions/seasons to assess the potential for competition for food between these two species. Grey seal diet will also be compared with the results from studies in 1985 and 2002 to investigate changes on an approximately decadal time scale.

This paper provides an update on the project to date (13 July 2012). Faecal samples are currently being processed and digestion experiments are being undertaken. No diet estimates are available yet.

Introduction

One possible contributing cause of the decline in harbour seal populations in some regions of Scotland during the last decade (Lonergan et al. 2007) is competition for prey with sympatric grey seals, numbers of which have increased greatly in the last few decades (SCOS 2011). Grey seal diet was last studied Britain-wide in 2002 and before that in 1985 (Hammond and Grellier 2006, Hammond and Harris 2006). There have been a number of regional harbour seal diet studies (reviewed in Cunningham et al. 2004) but, until now, there has been no large scale study. An important step towards assessing competition for prey between grey and harbour seals is to have comparable information on the diet of both species.

Methods

Scat collections for harbour seals were stratified by region and season (quarter of the year) and targeted all areas where major concentrations of seals occurred. Collections were made using a small boat or from land between April 2010 and May 2012.

Grey seal scat collections were focussed primarily on times and places where large numbers of scats had been collected in previous studies (breeding colonies and moulting haul-out sites).

For collections from mixed haul-out sites, molecular techniques are being used to identify scats to species (Matejusová et al. 2012). Potential sex differences in diet are also being investigated for September 2010 in the Ascrib, Isay and Dunvegan SAC (122 scats) and for July 2010 in the South-East Islay Skerries SAC (102 scats).

Experiments to estimate digestion coefficients, number correction factors and passage rates of fish otoliths and cephalopod beaks for harbour seals are using methods described by Grellier and Hammond (2005, 2006) and Hammond & Grellier (2006).

Progress

In total, 8354 scats have been collected across Scotland and England (Table 1). Sample sizes vary considerably among regions and seasons. Few scats were collected in Orkney and Shetland in autumn and winter 2010 so additional sampling was carried out in 2011.

In some regions/seasons, the number of scats collected was larger than needed for analysis so not all scats collected will be processed. Work has focussed initially on grey seal scats from Scotland, 83% of which have been processed and hard prey remains recovered (Table 2). Just over half of these prey remains have been identified and about 10% have been graded and measured and are ready for analysis.

In total, 6613 scats have been subsampled for molecular analysis (species/sex identification). To date 678 have been analysed to give species: 164 grey seals, 464 harbour seals and 50 undetermined. Sex identification of seal faeces at west coast SACs is currently being conducted.

Digestion experiments to estimate species-specific coefficients for partial and complete digestion of otoliths and beaks are on-going. Table 3 summarises experiments conducted to date.

Table 1. Total number of scat collected April 2010 - May 2012.

	Number of scats		
Region	**Harbour**	**Grey**	**Mixed haul-out site**
SE Coast	81	964	69
Moray Firth	367	100	216
Orkney	407	1066	420
Shetland	220	367	236
North Coast	202	109	32
NW & Skye	534	80	13
Outer Hebrides	128	466	84
West Coast	525	239	21
Strathclyde	5	2	9
England	518	851	23
TOTAL	**2987**	**4244**	**1123**

Table 2. Grey seal scats from Scotland selected for processing with numbers already processed in parentheses.

Region	Q1 Jan-Mar	Q2 Apr-Jun	Q3 Jul-Sep	Q4 Oct-Dec
SE Coast	99 (45)	38 (0)	100 (0)	125 (66)
Moray Firth	76 (66)		20 (0)	4 (4)
Orkney	419 (429)	64 (0)		308 (312)
Shetland	100 (160)			100 (63)
Minch				129 (126)
Monachs	62 (62)			47 (47)
N Out Hebs	100 (73)			101 (101)
N In Hebs	83 (83)	26 (26)		
S Out Hebs	28 (28)			70 (70)
S In Hebs	79 (77)		1 (0)	145 (96)
TOTALS	1046 (1023)	129 (26)	121 (0)	1041 (881)

Table 3. Number of experimental feeding trials for each prey species

Prey species	No. of Seals	No. of Trials
Cod	1	2
Dab	2	3
Haddock	1	2
Herring	4	10
Lesser sandeel	3	7
Norway pout	4	6
Plaice	4	8
Poor cod	4	7
Squid	3	3
Whiting	4	9

Deliverables

Estimates of grey seal diet composition and prey consumption are expected to be completed in March 2013. Harbour seal digestion experiment results are expected by spring 2013. Diet estimates for harbour seals are expected to be completed in December 2013.

Acknowledgements

The project is funded by the Scottish Government and supported by Natural England. SNH has provided support through a CASE PhD Studentship for LJW. Marine Scotland Science is supporting the molecular scatology.

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Dave Thompson

Movements of recently weaned grey seal pups in Orkney: preliminary results from telemetry studies in 2010.

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Introduction

The waters around and within the Orkney archipelago contain some of the most accessible regions of high tidal energy in the UK. The Pentland Firth area has already been identified as a potential major source of tidal electricity generation, including sites within both the main channel of the Pentland Firth and several high tidal flow channels within the islands. Orkney also has the UK's only established commercial scale tidal turbine testing facility in the form of the European Marine Energy Centre site at the Falls of Warness. This is therefore an area which already has active turbines and is likely to see large scale expansion to commercial scale arrays within the next few years.

Interaction between marine mammals and tidal turbines is seen as a potential problem for the developing industry. To date we do not know how or to what extent marine mammals will interact with turbines and are therefore unable to specify the likely scale, intensity or potential consequences of such interactions. The regulatory response to such uncertainty is a clearly justified precautionary approach. However, this poses major problems and significant costs from both conservation management and turbine operation perspectives.

Seals are often seen swimming within tidal rapids and there are suggestions that these may be important areas for them. However, our understanding of marine mammal distributions and their behaviour within high tidal energy areas is poor. Although high tidal energy areas may be important or even preferred, they usually represent only a small part of the range of any marine mammal species. Studies of more general, population-wide movement and behavior may not contain much information on usage in these areas. Because the oceanographic characteristics of these areas are unusual, it is not possible to extrapolate from observations made in other areas.

The level of interactions will not become clear until enough marine mammals are observed in the vicinity of operating devices. However, knowledge of the usual behaviour and usage patterns of these special sites in the absence of tidal turbines will provide a base line against which we should be able to assess the scale of potential interactions. In addition, having appropriate levels of knowledge about pre-deployment behaviour and movement patterns is a pre-requisite for assessing and hopefully quantifying the effects of device deployments in the near future.

A recent report compiled for SNH has identified seal behaviour in the Pentland Firth as a major data gap. The Sea Mammal Research Unit (SMRU) was contracted to carry out a telemetry-based study of the behaviour of grey seals at sea to begin to address this perceived data deficiency. The basic aims of the study were to track the movements and record the diving and swimming behaviour of individual grey seals, tagged at sites in Orkney, and relate the observed behaviours to the potential for interaction with future tidal turbine installations in the Pentland Firth and within the Orkney Islands. Data collection is ongoing, and only a brief summary is presented here. As a direct consequence of this tag deployment, additional funding has been provided by SNH for a complimentary deployment of similar tags on harbour seals in the same areas. These deployments will begin in April 2011 and the initial results will be described in the final report of this project (July 2011).

Methods

Choice of study animals

Grey seal pups are abandoned on land and therefore enter the water as completely naïve animals with no experience of foraging and no established movement patterns. Many of the breeding sites in Orkney are on islands close to strong tidal currents. Pups from these sites are likely to make their initial trips to sea in areas where there will in future be the potential for interaction with tidal generators during what is likely to be a vulnerable phase of their lives.

This study was focussed on investigating the initial foraging behaviour of weaned grey seal pups from two sites; Stroma in the Pentland Firth and Muckle Greenholm close to the EMEC site in the Falls of Warness.

Telemetry system: An investigation of the scale of possible interactions with tidal turbine devices requires information on the 3D movements of marine mammals. Grey seals spend the majority of their time (>85%) submerged and are hard to see even when at the surface in open water and they do not make loud or regular vocalizations so they cannot be accurately tracked using either visual or acoustic monitoring techniques. Previous studies indicate that grey seals make wide ranging movements between distant foraging and haul-out areas making it impossible to study individuals using any boat or land based monitoring method. In order to study the movement and dive patterns of seals at an appropriately fine scale, we used recently developed GPS Phone Tags, which combine GPS quality locations with efficient data transfer using the international GSM mobile phone network

These tags provide GPS quality (usually better than 10 m accuracy) locations at a user-controlled rate, together with complete and detailed individual dive and haul-out records. They are small, weighing 370 g which is <1% of an average seal pup mass. Data are relayed via a quad-band GSM mobile phone module when the animal is within GSM coverage. This results in relatively low cost, high energy efficiency, high data bandwidth and International roaming capability.

They incorporate a Fastloc GPS sensor that offers either the possibility of attempting a location at every surfacing or as frequently as required. Less than a second is needed to acquire the information required for a location. The tag also uses precision wet/dry, pressure and temperature sensors to form detailed individual dive (max depth, shape, time at depth, etc) and haul-out records along with temperature profiles and more synoptic summary records. Both location and behavioural data are then stored in memory for transmission when within GSM coverage.

For species such as grey seals that periodically come near shore – within GSM coverage – the entire set of data records stored in the memory can be relayed via the GSM mobile phone system. Visits ashore may be infrequent, so up to six months of data can be stored on-board the tag and these data can also be downloaded directly if the tag is retrieved.

Preliminary Results

Tagging: Initial plans to deploy transmitters in mid November were delayed because of the severe weather. A total of 18 GPS/GSM phone tags were deployed on weaned grey seal pups between the 12th & 14th December 2011 at 2 sites in Orkney

– 10 on Stroma - in Pentland Firth, close to proposed tidal array site
– 8 on Muckle Greenholm – adjacent to EMEC tidal test site

Details of sex and mass are presented in table 1. The delayed deployment did not affect the tagging work as sufficient pups were present on both islands, although the Muckle Greenholm animals represented the tail end of the pup production. In contrast there were still large numbers (>>50 pups)_on Stroma.

All animal handling and tagging methods are approved under SMRU's Home Office Licence. Standard transmitter attachment techniques were used. Briefly, seals were caught on land and physically restrained. No anaesthesia was required and tags were glued to cleaned, dried fur on the back of the neck using Cyano-Acrylate Locktite glue. Seals were released and left at their capture site. Most seals moved away a short distance before apparently settling down to rest. One animal on Muckle Greenholm and two on Stroma moved down onto the beach out of sight and may have gone straight into the water.

Initial movements: Highly detailed movement and dive behaviour records have been received from 15 of the tagged seals. Two seals on Stroma sent no information after leaving the breeding site. Because data are archived on the tag and only received after seals make contact with a phone cell we have no information on the fate of these two animals. One Muckle Greenholm animal washed ashore dead after 4 days.

The dive record from this seal indicated that it did not make any significant dives and floated to Westray with the transmitter submerged. The absence of any location data prior to its arrival at Westray means that it must have died very soon after entering the water. At present we have been unable to recover the tag and do not know what the cause of death was.

Almost complete records of location, diving depths and durations have been received from 15 of the 18 tagged seals. Data collection is continuing and the highly variable nature of the foraging trip durations means that we can not say which animals are still sending data.

Figure 2 shows the movements of all tagged seals up until 27th March 2011. Seals from the two sites have shown wide ranging movements with several seals foraging in areas over 400km from their tagging sites, visiting haulout sites as far afield as the Shiant Isles in the Minch and Fife Ness. In addition to wide ranging movements there are clear concentrations of tracks within the islands.

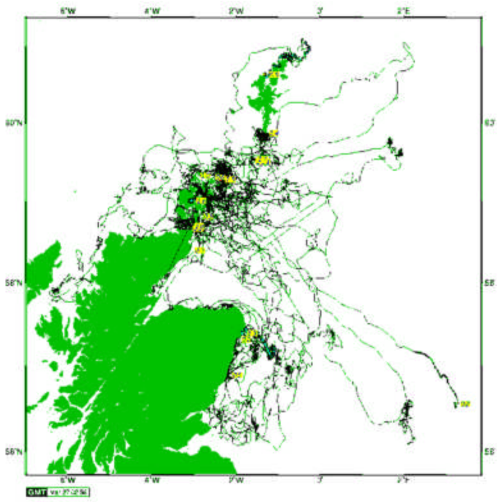

Figure 2 Swimming tracks of 15 grey seal pups. Yellow numbered labels indicate the most recent GPS positions obtained from each seal.

The tracks obtained so far indicate a wide range of behaviour patterns. Figure 3 shows a subset of seals that all made wide ranging trips away from their natal sites. Even within this group, there are wide differences in choice of foraging habitat with several animals moving along the coast, staying within 10 km of the coast for the majority of their time at sea. In contrast two animals swam directly out to sea and have not come within 40km of the coast line except when returning to haul out in Orkney.

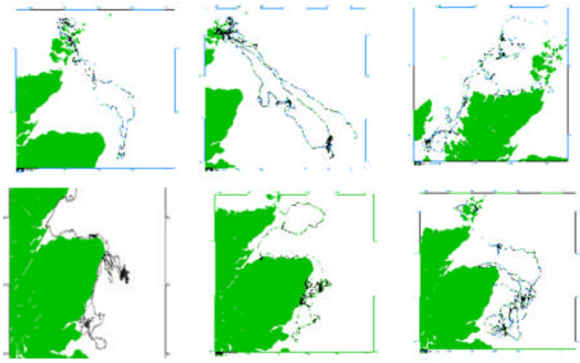

Figure 3 Swimming tracks of 6 grey seal pups making long-range trips away from their natal site.

Tag #	Sp.	Sex	kg	Date on	Time	location	lat	long
11865	Hg	F	35.0	12/12/2010	11:55	Muckle Green Holm	59.1311	2.8306
11871	Hg	M	36.6	12/12/2010	12:05	Muckle Green Holm	59.1311	2.8306
11806	Hg	M	35.0	12/12/2010	12:35	Muckle Green Holm	59.1311	2.8306
11874	Hg	F	40.0	12/12/2010	13:25	Muckle Green Holm	59.1311	2.8306
11867	Hg	F	34.0	12/12/2010	13:40	Muckle Green Holm	59.1311	2.8306
11869	Hg	F	42.0	12/12/2010	14:00	Muckle Green Holm	59.1311	2.8306
11872	Hg	M	40.0	12/12/2010	14:20	Muckle Green Holm	59.1311	2.8306
11873	Hg	M	45.0	12/12/2010	14:35	Muckle Green Holm	59.1311	2.8306
11621	Hg	F	38.0	14/12/2010	10:25	Stroma	58.6889	3.1111
11847	Hg	M	52.0	14/12/2010	10:40	Stroma	58.6889	3.1111
11843	Hg	F	37.0	14/12/2010	11:05	Stroma	58.6889	3.1111
11841	Hg	F	35.0	14/12/2010	11:30	Stroma	58.6889	3.1111
11870	Hg	M	30.0	14/12/2010	11:45	Stroma	58.6889	3.1111
11846	Hg	F	36.5	14/12/2010	12:35	Stroma	58.6889	3.1111
11849	Hg	M	49.0	14/12/2010	12:50	Stroma	58.6889	3.1111
11848	Hg	F	38.5	14/12/2010	13:05	Stroma	58.6889	3.1111
11844	Hg	M	43.0	14/12/2010	13:20	Stroma	58.6889	3.1111
11163	Hg	F	44.5	14/12/2010	13:45	Stroma	58.6889	3.1111

Table 1. Details of grey seal pups tagged in Orkney in December 2010

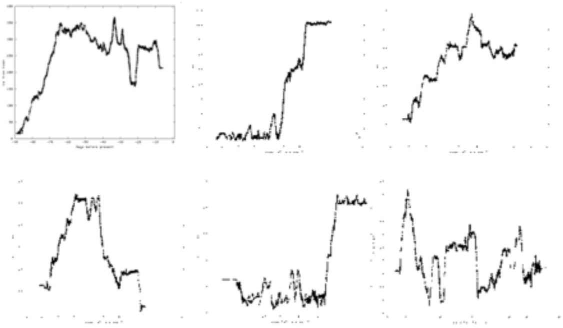

Figure 4 Distance from natal site for 6 grey seal pups that ranged widely during their initial foraging trips.

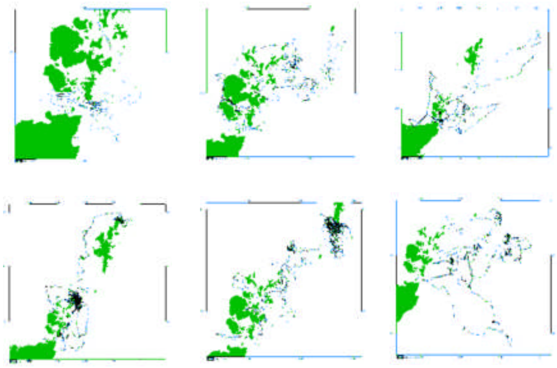

Figure 5 Swimming tracks of 6 grey seal pups that concentrated their foraging efforts in and around the Northern Isles.

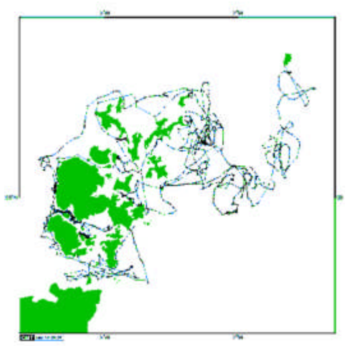

Figure 6 Expanded view of one of these which swam repeatedly through the tide races in the Pentland Firth, the Falls of Warness, Eynhallow Sound and the entrances to Scapa Flow.

Figure 5 and 6 show a different subset of 6 seals that concentrated their foraging efforts within and around the Orkneys and Shetland. All 6 seals made extensive trips but spent a higher proportion of their time within the archipelago and therefore made repeated movements through channels with high tidal flows.

Dive behaviour

In addition to high resolution location data to allow interpretation of movements the tags also send high resolution dive and haulout behaviour information. Fi gure 7 shows summary dive records of four seals. The blue traces represent dive depths, showing the maximum depths of each dive. Yellow dots on these traces indicate temperature profiules were transmitted for that dive. The lower trace on each plot gives a summary in terms of haulout time (green bars) diving below a 4m dive threshold (yellow bars) and shallow or surface swimming (blue bars). These data are downloaded periodically and because the trips by these seals are so long it will take some time for the full dive data set to be downloaded. However, a preliminary examination shows that seals are diuving regularly to depths as great as 120m for extended periods. There are indications that withing the islans and in high tidal energy areas the dive patterns are less regular and dive profiles indicate continuous swimming during V shaped dives typical of transit swimming in open water (Figure 9). However a detailed analysis of these data will not be possible until the detailed records are complete.

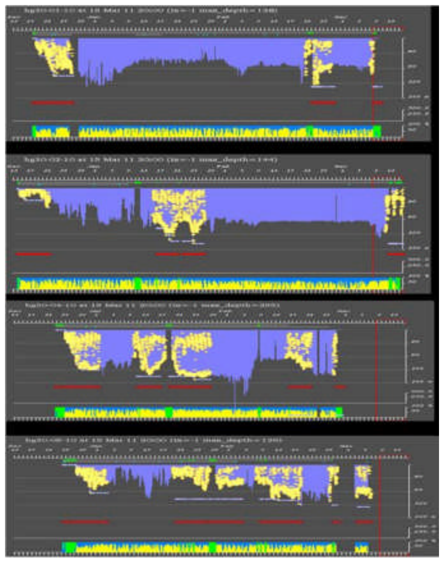

Figure 7 . Dive and haulout records of 4 specimen seals showing dive depths (upper blue trace) and 6 hour block summary data of haulout (green bars), diving below 4m (yellow bars) and surface swimming or resting (blue bars) in the lower trace in each plot.

The final analysis will include a description of the number and specific locations of each time a seal crosses an area, or line of interest in any specified location. This can be achieved by linear interpolation between GPS locations to allow us to estimate where seals pass through any pre-defined section of the ocean. Specific areas of interest will be chosen through consultation with Marine Scotland. This analysis will be extended to incorporate all previous tag deployments (although the low location quality of older ARGOS data may reduce the value of that exercise) as well as this study and up-coming harbour seal tagging work.

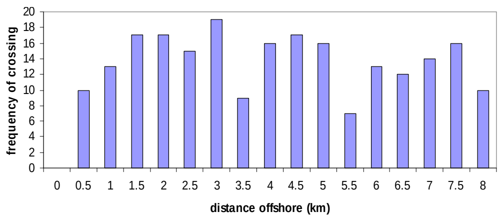

Figure 8 shows an example of this analysis for a small sample of grey seal pups tagged in North Wales crossing a line off Anglesey where a small turbine array is planned.

High resolution dive data can then be incorporated to determine where seals are spending their time in terms of position in the water column Fig 9 and 10.

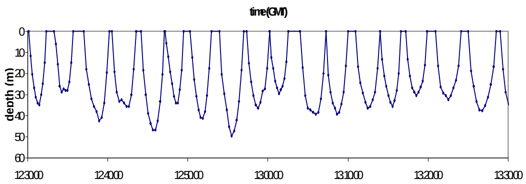

Figure 9 Dive profiles of seal 9 swimming in tide rip.

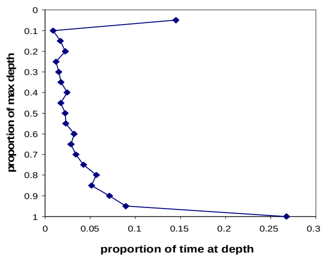

Figure 10 Proportion of time spent at different proportions of the maximum depth in foraging dives.

Combining the X-Y data from GPS and Z data from depth profiles and again linearly interpolating both position and depth we can plot the 2D distribution of crossing points for any section of ocean for which we have data. Fi gure 10 shows the crossing patterns of two seals off N Wales, but the same analysis will be provided for the Orkney seals in the final report.

3.4. Suvivorship

In addition to movement and dive behaviour data, there may be information in the transmission patterns relating to the mortality schedule of the sample of pups. To date we do not have definitive final transmission times for many of the pups, but figure 11 presents the data on the assumption that seals not heard for the last 30 days are probably dead. At present over half the pups were definitely still alive and sending back information in May. This is more than expected given the high juvenile mortality in grey seals in general and an expected increased mortality as the population has approached its carrying capacity in some way.

Although it is tentative, the data suggest that pups making longer trips are more likely to have survived the initial period of naïve foraging. This will need further investigation and a more rigorous analysis will be presened later, incorporating similar information from simultaneous tracking studies of Welsh grey seal pups.

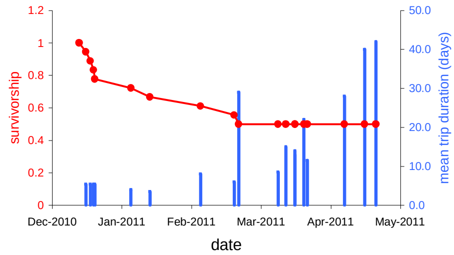

Figure 11. Putative times of death of the grey seal pups tagged in Orkney in 2010 together with their mean foraging trip durations.

Conclusion

This is only a preliminary progress report and a full analysis will be presented later. However it is clear that the tag deployment has been successful and has provided a large quantity of high resolution dive behaviour, movement and haulout information. The observed initial foraging behaviour patterns are highly variable and there appears to be some association between length of foraging trip and probability of survival during the early period of independence. It is not yet possible to determine if this is the case and if so whether it is trip duration or location that is linked. The data will allow us to estimate the rate at which tagged grey seal pups traveled through areas of potential tidal turbine deployments. In conjunction with the extensive information on local pup production and summer haulout distribution it should also allow us to estimate the likely overall rates of juvenile seals passing through such areas.

Dave Thompson

Studies of harbour seal behaviour in relation to tidal renewable energy developments: movements and diving behavior of harbour seals in Kylerhea.

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Introduction

The UK is committed to a massive increase in renewable energy generation over the next 20 years and wind, wave and tidal power will play a major role in meeting these targets. The tidal energy in the waters around the Inner and Outer Hebrides and Orkney Islands represent a considerable resource that will necessarily form part of Scotland's offshore renewable energy programme. There is however concern over the potential for interaction between marine mammals and tidal turbines. The most obvious, and probably the most important interaction in terms of public perception, is the potential for injuries or fatalities resulting from direct contact with moving parts of tidal power devices (Linley *et al.* 2009; Wilson and Gordon 2011).

Devices and marine mammals must coincide in both space and time in order for any such effects to occur. Currently we lack any hard information on the behaviour of marine mammals during such proximate interactions so we can only estimate the potential for collisions. How animals act in terms of avoidance or attraction towards devices and their ability to evade collisions will scale the potential collision risk assessment. Understanding behavioural response to an operating tidal-OREG is a priority.

Two models have been proposed for estimating the risk of collisions between marine mammals and tidal turbines in UK waters: a modified version of a model developed to estimate the number of birds that could be expected to collide with onshore wind farms (Band *et al.* 2007) and a model (Wilson *et al.* 2007) based on a movements and interactions model developed to investigate predation by zooplankton (Gerritsen and Strickler 1977).

Because of the lack of information on avoidance and/or evasion behaviour both models incorporate one important assumption: that the patterns of movement of marine mammals will be the same in a particular place irrespective of the presence or absence of a marine renewable energy device. That is, marine mammals show neither attraction nor avoidance behaviour and make no attempt to evade the moving parts. Under this assumption the number of marine mammals impacted can be derived from an estimate of how many will pass through the footprint of a device scaled by the likelihood of being hit by a blade based on the transit time of the animal and the rotation rate and number of the blades.

Several factors are likely to influence both the likelihood and severity of such contacts (Wilson *et al.* 2007). In a recent review for Marine Scotland (MR1 & MR2 of the MMSS/001/11 project) we identified a set of information requirements to refine such estimates. To assess the probabilities of such occurrences we need information on:

1) The characteristics of the device, e.g. rotation speed, blade length and number, position in water column.
2) The short term and seasonal movement patterns of animals
3) The size of the population at risk
4) The dive patterns, depth usage and small scale movement patterns of individuals
   i. Reactions to presence of devices Avoidance/ Attraction of animals to the turbines.
   ii. Evasion behaviour in close proximity to devices.

The tidal energy in the waters around the Inner and Outer Hebrides and Orkney Islands represent a considerable resource that will necessarily form part of Scotland's offshore renewable energy programme. There are planned/potential tidal turbine developments on the west coast, particularly in the Sound of Islay and Kylerhea and in the Pentland Firth and waters around the Orkney Islands. Both areas are known to be used by harbour seals and harbour seals are the main qualifying feature for the South East Islay SAC. To date there is little information on the movements of harbour seals in the vicinity of these sites and there is a perceived requirement for information on the behaviour of seals within these high tidal energy areas.

In response to these perceived data gaps Marine Scotland and SNH commissioned the SMRU to carry out a series of telemetry based studies of movements and diving behavior of harbour seals in high tidal energy regions that will address aspects of items 2 and 4 above.

The aims of the overall project are:

1. To describe the movements and diving behaviour of harbour seals in the Pentland Firth, specifically those animals using haulout sites in the vicinity of Stroma and the proposed Inner Sound tidal array site.
2. To describe the movements and diving behaviour of harbour seals around Islay, specifically those animals using haulout sites in the vicinity of the South East Islay SAC and in the Sound of Islay.
3. To describe the movements and diving behaviour of harbour seals in the waters surrounding the tidal rapids at Kyle Rhea.
4. To describe the movements and diving behaviour of harbour seals using haulout sites in the Tay and Eden SAC.

This report presents a summary of the data collected during the initial transmitter deployments in the Kylerhea study area. As such it forms one of a series of interim reports describing the movements and diving behavior of seals in each area. It is designed simply to present the information most likely to be of use in assessing the potential impacts of any tidal turbine deployments in an easily accessible format. A comprehensive analysis of data from the combined study of both grey and harbour seals at various sites around Scotland will be presented to SNH and Marine Scotland in November 2013.

Methods

In order to study the movement and dive patterns of seals at an appropriately fine scale, we used purpose built GPS Phone Tags, which combine GPS quality locations with efficient data transfer using the international GSM mobile phone network. These tags provide GPS quality (usually better than 10 m accuracy) locations at a user controlled rate, together with complete and detailed individual dive and haul-out records. They are small, weighing 370 g which is <1% of an average seal pup mass. Data are relayed via a quad-band GSM mobile phone module when the animal is within GSM coverage. This results in relatively low cost, high energy efficiency with a high data bandwidth.

Due to limited battery capacity there is a direct tradeoff between the temporal resolution of the location data and the life of the transmitter. In order to produce location data from the tagging date to the moult when tags are expected to fall off we set the tags to collect a GPS location fix at 8 minute intervals.

Seals were caught using a combination of rush and grab techniques and tangle nets at haulout sites. Seals were anaesthetized with an intravenous dose of a Tiletamine-Zolazepam mixture (Zoletil) and tags were glued to cleaned, dried fur on the back of the neck using a cyano-acrylate contact adhesive (Loctite 422). Seals were released and left to recover on shore close to their capture site.

An initial catching attempt in October 2011 was abandoned due to lack of available study animals. Seals were scarce or completely absent from the haulout sites within Kyle Rhea throughout the winter 2011-2012 and early spring 2012. Significant numbers began to appear in mid April 2012. This pattern of absence of seals in autumn and winter and increasing numbers using haulout sites in Kylerhea throughout the spring and summer appears to be a consistent annual pattern (A. Law pers com). Table 1 gives the tagging details of seals caught at haulout sites in the high tidal energy site within Kyle Rhea in April 2012.

Table 1. Tagging data and morphometrics for harbour seals fitted with GPS/GSM tags in Kylerhea in April 2012.

Seal i.d.	Date	Tagging Location	Sex	Age.Class	Mass(kg)	Length(cm)	Girth(cm)
350	17/04/2012	Kylerhea, Skye	M	Adult	72	151	89
351	22/04/2012	Kylerhea, Skye	M	Adult	70.4	139	99
360	21/04/2012	Kylerhea, Skye	M	Adult	87	155	108
364	21/04/2012	Kylerhea, Skye	M	Adult	77.2	148	102
365	27/04/2012	Kylerhea, Skye	F	Adult	74.6	134	105
368	27/04/2012	Kylerhea, Skye	F	Adult	83	140	107
370	23/04/2012	Kylerhea, Skye	M	Adult	92	154	112
376	18/04/2012	Kylerhea, Skye	F	Adult	83.4	138	106
394	18/04/2012	Kylerhea, Skye	M	Adult	79.6	147	105

Preliminary Results

General movements

Figure 1 shows the tracks of all nine seals between April and July 2012. Only two seals moved out of the channels between Skye and the mainland. One seal made an initial trip to the North, swimming directly to the Butt of Lewis where it remained for 4 days before returning to Kyle Rhea where it remained for the rest of the tracking period. A second seal moved south around the south coast of Skye to an area 10km east of South Uist before returning via the Small Isles. It then remained in the Sound of Sleet for the remainder of the study period. All other seals stayed within 20 km of their capture site and made repeated transits through the narrows at Kyle Rhea.

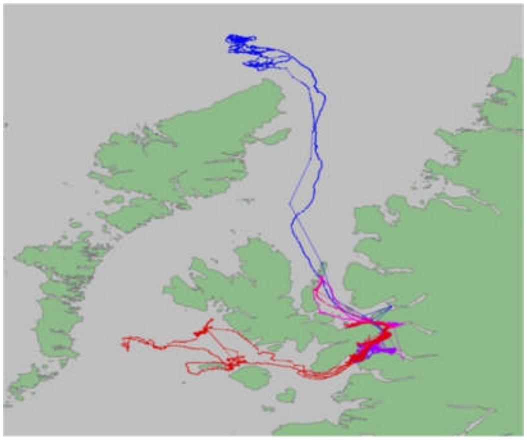


Figure 1. GPS positions and swimming tracks of nine harbour seals tagged in Kylerhea. The plot shows data from the tracking period between late April and late July 2012. Only two seals moved out of the channel between Skye and the mainland.

Figure 2 shows the very high density of tracks of animals moving through and/or foraging within the channels between Skye and the mainland. Figure 3 shows the distribution of GPS derived surfacing positions of all nine seals within the tidal rapids surrounding the proposed turbine array site in the southern part of Kylerhea. This area included the capture sites for all nine seals and therefore also includes a substantial number of haulout records. However, when filtered to only include location records while swimming, the nine tagged seals spent 57% of the study period within the narrows at Kylerhea (between $57^{o}13'14"N$ and $57^{o}13'N$) and all seals spent at least 35% of their time in the narrows (table 2).

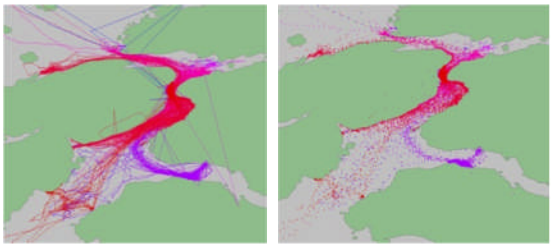


Figure 2. GPS positions and swimming tracks of nine harbour seals tagged in Kylerhea. The plot shows data from the tracking period between late April and late July 2012 and shows the intense movement activity within the channel between Skye and the mainland, with most activity occurring between the Kyle of Lochalsh and the northern end of the Sound of Sleight .

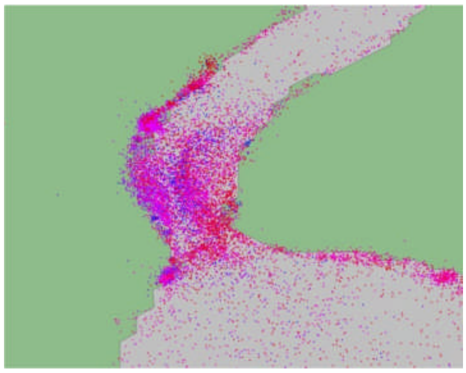


Figure 3 Distribution of GPS derived surfacing positions of all nine seals within the tidal rapids surrounding the proposed turbine array site in the southern part of Kylerhea.

Fine scale movements

The rate at which seals pass through the area swept by the blades of a tidal turbine is an important parameter which sets the upper limit on the potential for direct physical interactions with the device. The data from the GPS and depth sensors can be used to estimate the number and the depth and geographical positions at which seals pass through a specific section of the channel.

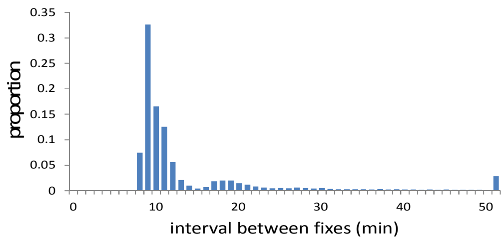


Figure 4 Frequency histogram of the intervals between successive GPS position fixes while seals were in the water. N= 24990, mean = 13.8 minutes.

Table 2. Estimated proportion of time spent within the narrows at Kylerhea (between 57°13'14"N and 57°13'N) between late April and late July 2012.

Seal i.d.	GPS Location fixes within Kylerhea	Total GPS location fixes	Proportion within Kylerhea	Duration of tag life (days)
350	916	1969	0.47	77.8
351	1692	2080	0.81	42.7
360	2779	5569	0.50	92.9
364	1696	1884	0.90	99.2
365	1993	2580	0.77	45.5
368	1792	4118	0.44	48.5
370	101	252	0.40	14.7
376	1631	4663	0.35	57.1
394	866	1874	0.46	30.6
total	**13466**	**24989**	**0.57**	**508.7**

The GPS position fixes obtained by the tag indicate the seals' XY positions to an accuracy of approximately +/- 10m. However, the tags were set to sample GPS only when at the surface and in order to conserve battery power and provide a useful tag life they were further restricted to sampling at intervals of at least 8 minutes. Not all surfacing events produce successful GPS fixes, and the combination of these restrictions produced a sampling rate of approximately one successful GPS fix every 13 minutes (figure 4) but with 57% of gaps being between 8 and 11 minutes.

The pressure sensors on the tags provide a 10 point depth profile for each dive with an accuracy of +/- 1m and the tags also transmit the start and end times of each dive. The location and depth of each seal can then be estimated at any time by interpolating the XY position assuming direct straight line movement between position fixes and linearly interpolating between successive time depth records.

As an example of the type of data available we estimated the number of times and the depths at which the tagged seals crossed an arbitrary line drawn across the narrowest point of the channel at Kylerhea. The example line chosen was an east west transect across the channel at the southern boundary of the array box drawn in the MCT Environmental statement (lat 57.229° N, long 5.656°W to 5.665 °W) (Figure 5). The resulting line was approximately 550m long. A depth profile for the transect was extracted from the SEAZONE-TRUDEPTH topography database.

Table 3 The number of times individual tagged seals crossed an arbitrarily chosen line across the south end of Kylerhea channel.

seal id	tag life (days)	crossings	rate(transits/day)
364	35.4	42	1.19
394	31.8	77	2.42
350	50.7	37	0.73
351	28.7	88	3.07
360	92.5	142	1.54
365	33.8	148	4.38
368	48.3	155	3.21
370	13.7	3	0.22
378	56.5	173	3.06
Total	391.4	865	2.21

This preliminary analysis of the data from the relatively small sample of nine tagged seals over a total of 391 seal days produced a total of 865 crossings/transits of the line. All nine tagged seals crossed the line several times during the study at an average rate of 2.2 transits per seal per day (Table 3)

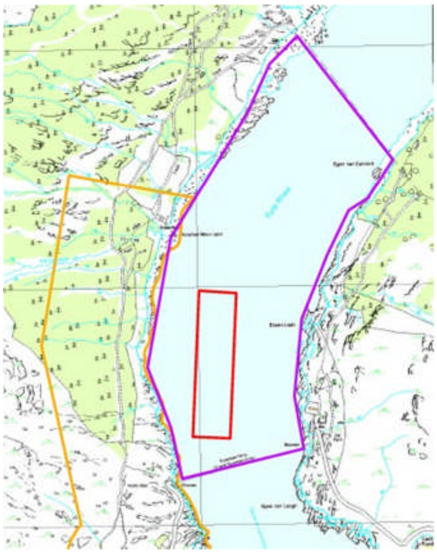


Figure 5 Map of the Kylerhea study site with the approximate locations of the proposed four turbine tidal array site indicated by the red rectangle and the arbitrary transect line indicated by the black arrow. (courtesy of MCT.)

Figures 6 and 7 show the estimated locations and depths of all the crossings by all nine seals. The points at which the seals were estimated to have crossed the line were roughly evenly distributed across the central section of the channel both in terms of distance from shore (figure 6) and swimming depth (figure 7). However, it is clear from the fact that significant numbers of crossing points were unfeasibly deep that there must be substantial interpolation error in the location and depth estimates.

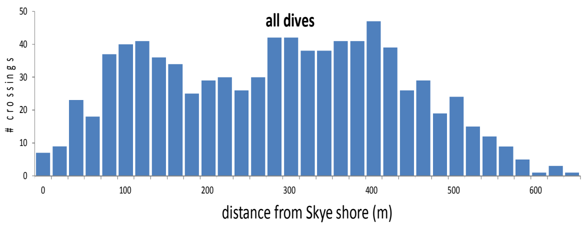


Figure 6 Distribution of distances from shore (defined as distance from the Skye shore) at which seals crossed an arbitrarily defined line stretching across the narrowest point of Kylerhea at the southern edge of the Array Box.

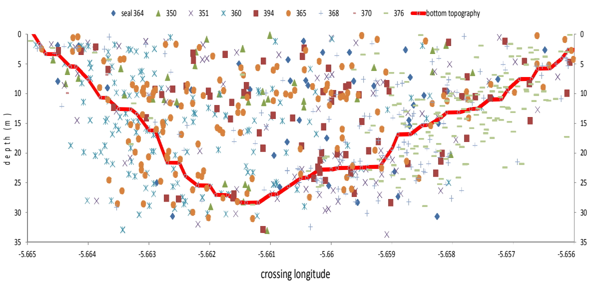


Figure 7 Depth and distance from shore of seals crossing an arbitrarily defined line stretching across the narrowest point of Kylerhea at the southern edge of the Array Box.

The intervals between locations and the relatively small errors in the position fixes from the Fastloc GPS (less than 50m) means that there can be potentially large interpolation errors in the locations and therefore also on the interpolated depths at any specific time between the position fixes. To reduce these effects we sub-sampled the data to include only those crossings that were estimated to have occurred in dives immediately before or after a position fix. In effect this meant those dives with a GPS position fix within approximately 2 minutes of the time they were judged to have crossed the line.

Figure 8 shows the frequency of crossings for this reduced dataset. There is a clear bimodal pattern with fewer transits in the centre of the channel. Figure 9 shows the depth distribution of the reduced dataset. Again the pattern of reduced transits in the deeper central section is apparent as is the low number of mid water transits in the deeper water section. This area of apparently reduced activity is both the deepest section of the channel and also the area with the highest flow rates (figure 10).

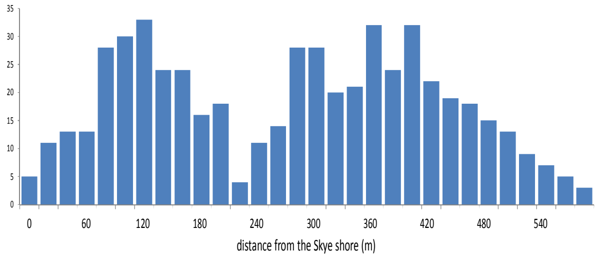


Figure 8 Distribution of filtered distances from the Skye shore at which seals crossed an arbitrarily defined line stretching across the narrowest point of Kylerhea at the southern edge of the Array Box.

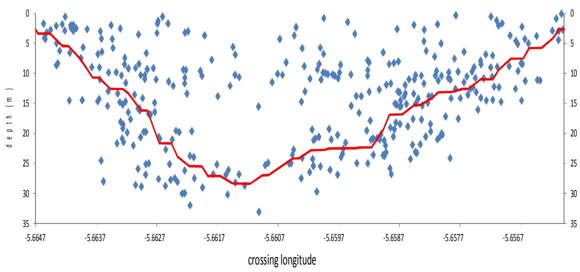


Figure 9 Depth and distance from shore of seals crossing an arbitrarily defined line stretching across the narrowest point of Kylerhea at the southern edge of the Array Box, for filtered data.

Although these data do not provide sufficient spatial resolution to identify direct passage through a small window equivalent to a turbine, they can be used to estimate the general pattern of transits through a specified area.

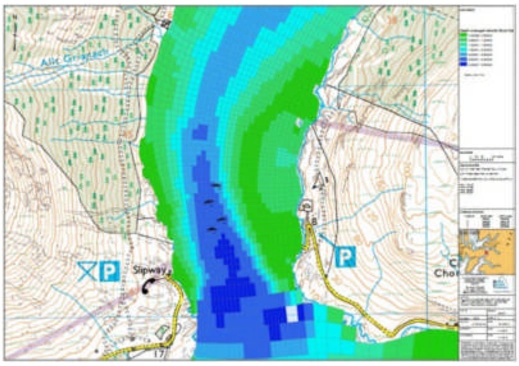


Figure 10 Map of the rates of flow at peak flood tide in the Kylerhea study site with the approximate locations of the four proposed tidal turbines indicated by the black symbols and current speed indicated by colour, with green representing low flow rates and blue representing higher rates. (reproduced from MCT.)

Dive behaviour

Figure 11 shows examples of dive profiles for three individual seals. The depth profile itself is generated from eleven depth points (2 start and end points at the surface and 9 evenly spaced through the dive). The plot also shows the times of haulout periods between bouts of diving. The plots also include an index of tide height and of flow. As seals moved rapidly throughout the channel the times of local high water (HW) and low water (LW) are always approximations. For this initial examination we estimated local HW and LW times as being equidistant between the HW and LW times at the Kyle of Lochalsh and Glenelg Bay (the average difference between the times at these two sites was only 24 minutes). The index of tidal flow was derived in a similar way, but assumed that the minimum flow occurred around 45 minutes after local HW or LW times. No attempt was made to assign an estimated speed because local flow conditions vary over short ranges within the range of movements between successive location fixes. The red trace on each plot in Figure 11 is therefore simply an index of higher and lower flow rates. Plots of the seal's swimming tracks for the periods shown in the depth profiles are presented alongside each time depth profile.

The initial impression is that the dive patterns are highly variable both in terms of the shapes of dives and the depths of dives within particular dive bouts/foraging trips.

The seals that spent some time outside the core study area in Kylerhea performed dives to the local sea bed depth, with regular diving to depths of 150m+(figure 11 seal 394: b & c) . However, within the Kylerhea narrows dives were restricted to depth of less than 40m (figure 11 seal 394 a; seal 351 a; seal 364 a & b), consistent with the local bathymetry in Kylerhea. Within individual dive bouts there appeared to be little or no consistent pattern to the diving with rapid and frequent changes in maximum dive depths (figure 11 seal 351 b; seal 364 c,d & e). In each case the changes in depth profiles were at least consistent with benthic diving given the the rapid and apparently pattern of movements within Kylerhea narrows. The only significant periods of continuous shallow diving to depths of <10m were associated with periods spent close to the haulout sites ((figure 11 seal 364 d).

Figure 12 shows the proportion of time spent at different depths, expressed as a proportion of the maximum depth, within individual dives. This clearly demonstrates that the majority of time is spent at the bottom of the dive (41% of time within 90% of max depth) or at the surface (21% of time at the surface). However, the complexity of the topography and the interpolation errors in location of each dive makes it impossible to determine what proportion of these dives reached the seabed and it is therefore not possible to say where exactly in the water column the dive activity occurred.

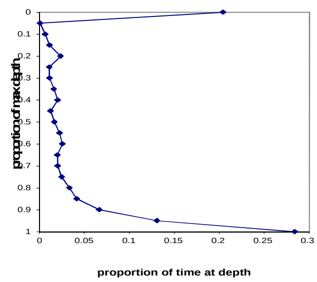
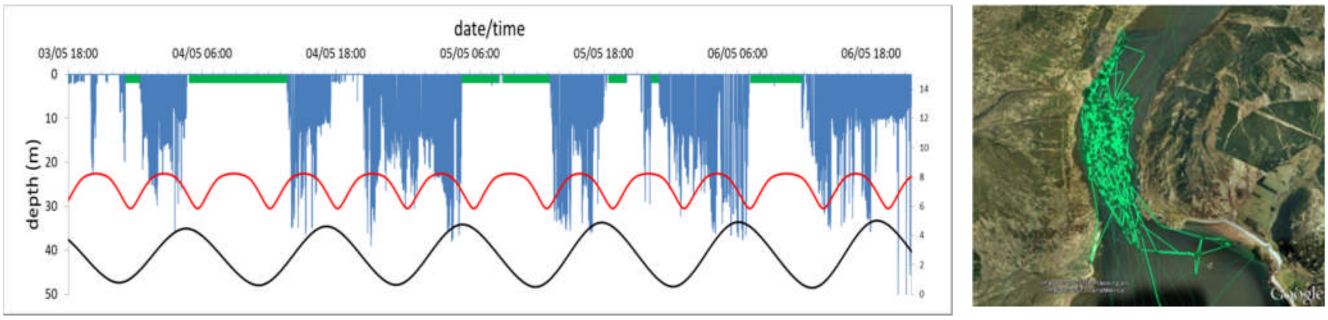


Fig 12. Proportion of time spent at depth expressed as a percentage of the maximum depth in each dive for dives >2minutes duration in Kylerhea.

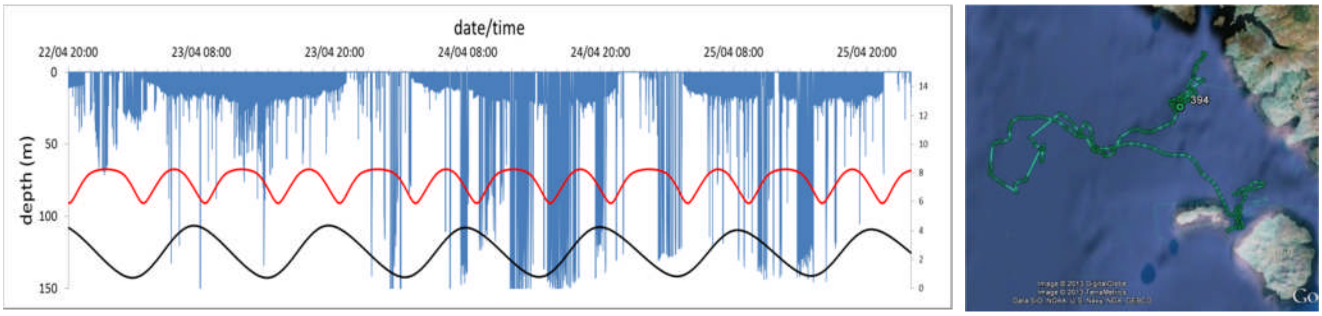
Figure 11 Examples of dive profiles for three individual seals. Blue lines represent time depth profiles, green bars along the top axis represent haulout periods, black sine waves are an index of tide height and red lines are an approximate index of flow speed. The Google Earth plots show the seal's swimming tracks for the periods shown in the depth profiles. Details given in the text.

Seal 394

a

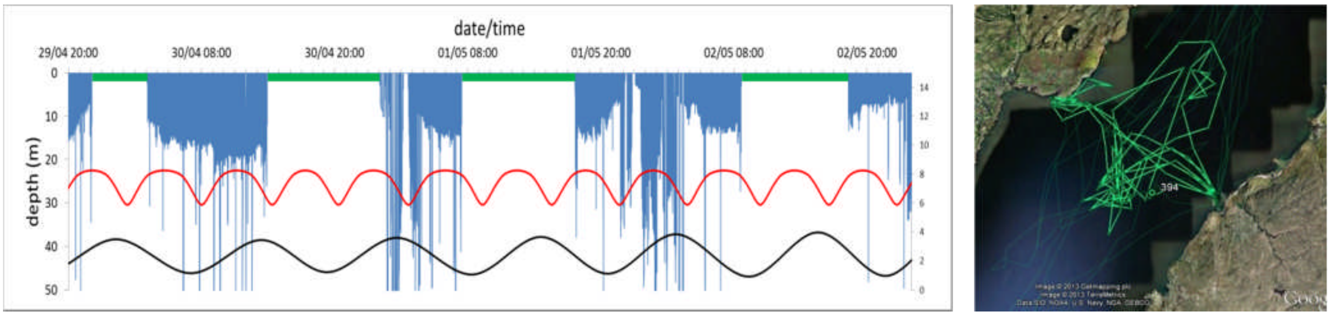


b

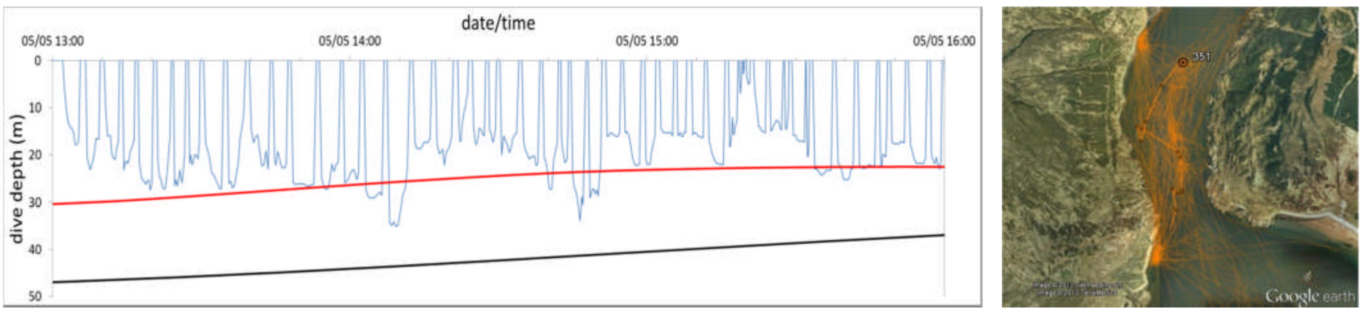


Seal 351

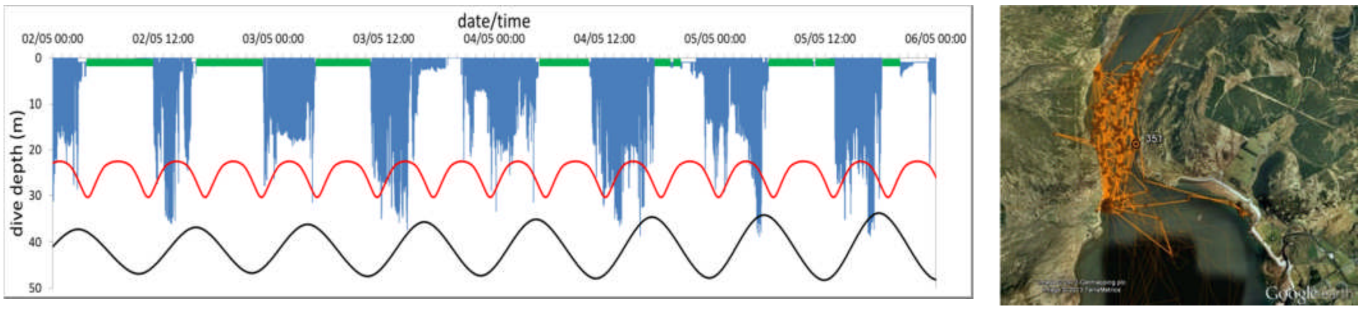
a



b

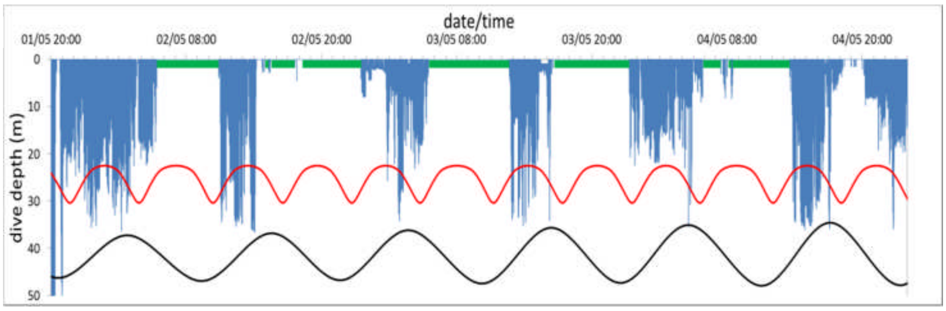


c

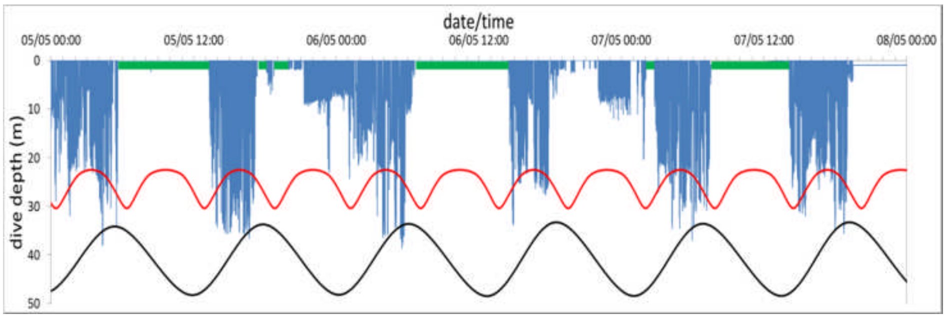


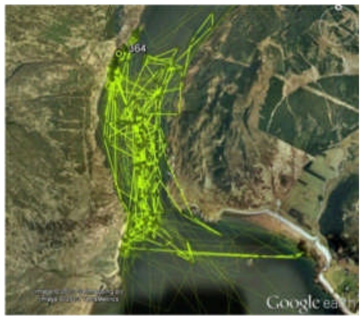
Seal 364

a

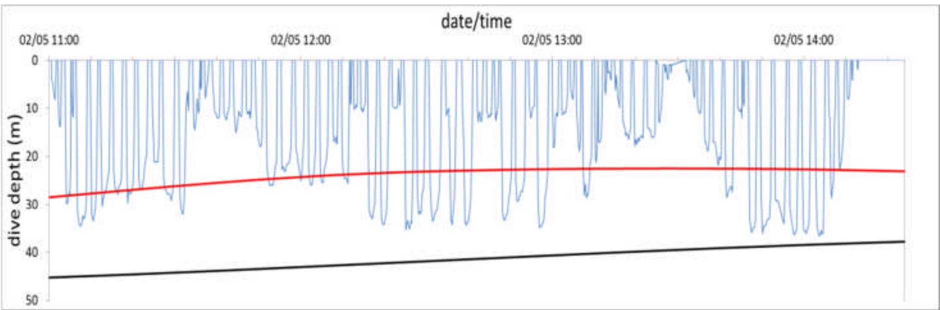


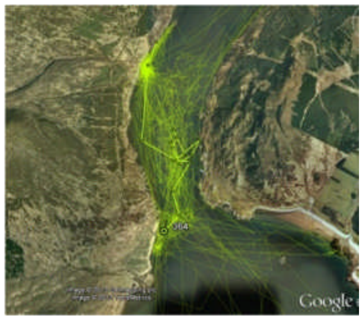
b



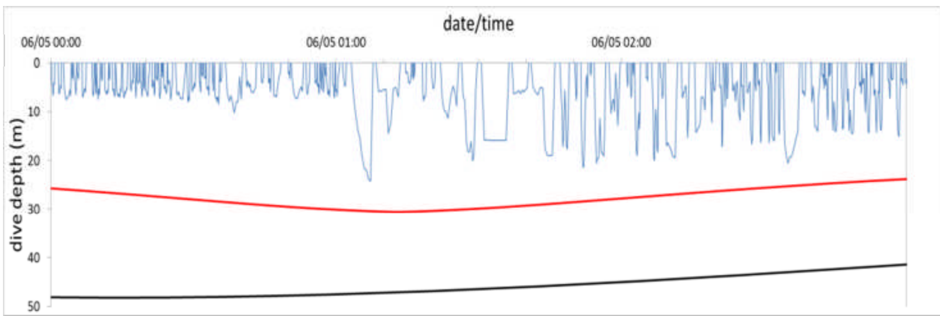


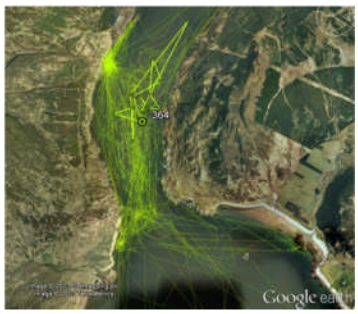
c



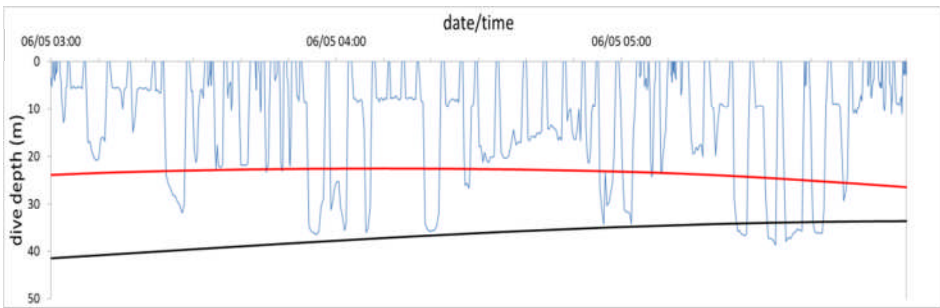


d





e



Dive behaviour relative to tidal flow.

Figure 13 shows frequency histograms of dive durations for dives within Kylerhea. Figure 14 shows an index of dive squareness (the area of the time depth profile expressed as a proportion of the area of a profile assuming the seal spent all the time at the maximum depth). In both cases the data have been split into dives occurring within +/- 1 hour of slack water. Time of slack water was estimated by assuming that it occurred approximately one hour after local high or low water times (assumed to be equidistant between HW and LW times for Kyle of Lochalsh and Glenelg Bay).

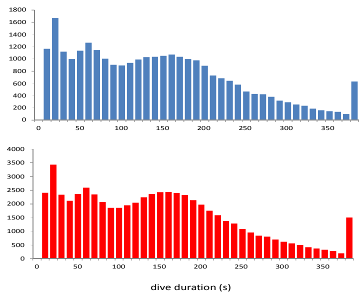


Figure 13 Frequency histograms of dive durations for all dives occurring within Kylerhea. Blue represents dives in low flow and red represents dives in high flow periods (see text for details).

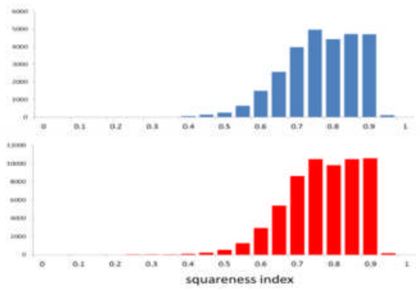


Figure 14 Frequency histograms of dive squareness index for all dives occurring within Kylerhea. Blue represents dives in low flow and red represents dives in high flow periods (see text for details).

In both cases the pattern for the two states of tidal flow were similar, suggesting that dive behaviour in terms of dive durations or proportion of time spent at the bottom of the dive does not vary with stage of tide.

Timing of haulouts and foraging trips within Kylerhea.

A cursory examination of the timing of diving bouts and haulout events in figure 11 suggests that there may be a relationship between haulout times and local HW times. The timing of swimming and hauling out within the high tidal flow area is important for scaling collision risk. The transmitters log the start and end times of haulout events and transmit these along with a haulout identifier number to show when haulout events have been missed in the data record. To examine the relationship between haulout events and local tidal flow we plotted a frequency histogram of haulout start times expressed as time from nearest HW time (Figure 15).

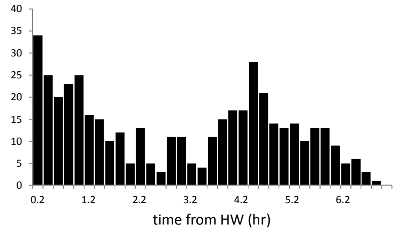


Fig 15. Frequency histogram of the start times for all haulout events within Kylerhea, relative to time of local HW, by all seals.

There is a clear bi-modal pattern to the times of haulout relative to the stage of tide, with one peak centred on local HW and another centred around 4.5 to 5 hours from HW. The simplest inference is that the seals were tending to haulout at or close to slack water in Kylerhea during April to July. However, that period includes the pupping and breeding season for harbour seals. We therefore split the haulout data into pre-breeding (defined as April and May) and breeding (June and July). The bimodal pattern appears to be largely due to a shift in timing of the start of haulouts from around HW in April-May to LW in June July (figure 16).

Commensurate with the change in haulout timing there was also a shift in the durations of haulout events (figure 17) and foraging trip durations (figure 18). The mean durations of haulout events in Kylerhea increased from 3.9hr in April-May to 5.2hr in June-July and the durations of diving bouts/foraging trips increased from 9.1hr in April-May to 18.1hr in June-July.

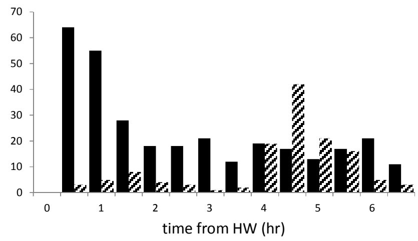


Fig 16. Frequency histogram of the start times for all haulout events within Kylerhea, relative to time of local HW, split into pre-breeding (solid) and breeding (striped) seasons.

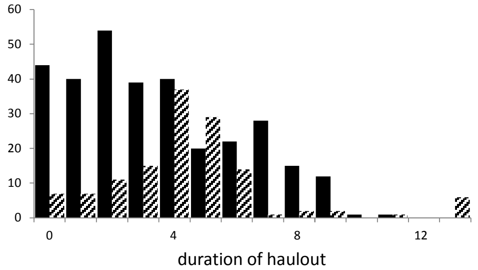


Fig 17. Frequency histogram of the durations of all haulout events within Kylerhea, split into pre-breeding (solid) and breeding (striped) seasons.

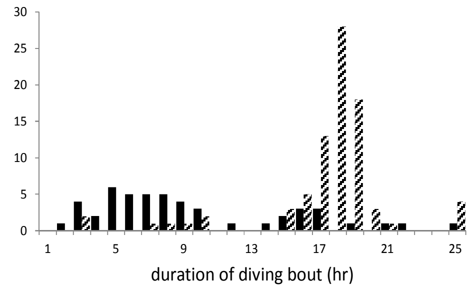


Fig 18. Frequency histogram of dive bouts/foraging trips that both started and ended in Kylerhea, split into pre-breeding (solid bars) and breeding (striped bars) seasons.

Discussion/ Conclusions

- Fine scale telemetry data has been collected from adult harbour seals during the summer period when there are significant numbers of seals in Kylerhea. It is not known why seals are present only in the summer months in Kylerhea, but the arrival of large numbers of seals and their intense diving activity within the channel suggests that there is a concentrated and valuable seasonal food resource during the summer in Kylerhea.
- Only two of the tagged seals made extensive movements outside the channels between Skye and the mainland and even these two seals spent the majority of the tagging study within the channels. The remaining seven seals spent their time foraging in the tidal channels. Over half of all seal swimming activity occurred within the narrows at Kylerhea.
- The extensive (in some cases exclusive) use of tidal race areas, seeming to move forwards and backwards with the tide and repeatedly diving to or close to the bottom. suggest that the seals were using the tidal rapids for foraging.
- Movement patterns within Kylerhea suggest that seals are moving in and out of the current in order to remain within the channel and the pattern of diving is highly variable within the narrows with a wide range of dive shapes and variable maximum dive depths suggesting either extensive mid water diving or rapid changes in bottom topography as the seals move around the channel.
- Despite the difficulties in assigning seabed depths to individual dive locations it seems likely that some dives at least are going to or close to the seabed. In most dives the majority of the time/effort is spent at or close to the maximum depth (>40%) or at the surface (20%), with rapid transit between the two. If these are to the bottom then the dive patterns suggest that seals will be spending little time in mid-water when foraging. Similar patterns have been recorded in juvenile grey seals exploiting tidal rapids around North Wales (Thompson 2012).
- Examination of the fine scale movements of seals in the tidal rapids in Kylerhea suggests that when passing through such an area seals are widely distributed in the channel with respect to both depth and distance from shore.
- All of the seals tagged in Kylerhea swam repeatedly through the channel in the vicinity of the proposed turbine deployments. We presented an example of how seals were distributed in the water column as they passed through one section of the channel. The filtered data shows a clear bimodal pattern in transits with respect to distance from the shore, with transits being less frequent in the central, deeper section of the channel. In addition, there appears to be a reduced density of transits in mid-water through the central deep channel. This would be an expected consequence of the dive profile patterns and has clear and important implications for estimating collision risk. However the interpolation error due to timing of GPS fixes and the small but significant GPS position error means that the transit depth and location data will still contain substantial error. A higher GPS sampling rate with fixes at every surfacing will substantially improve such estimates (see below).
- Harbour seals make extensive use of the high tidal energy area in Kylerhea throughout the summer months. Under the simplifying assumption that the presence of turbines will not affect diving behaviour and movement patterns there would clearly be a potential risk of collision with tidal turbines deployed in Kylerhea. Some seals remained in the vicinity of the sites for many weeks and made repeated transits through the proposed tidal array area.
- One important caveat that applies to any baseline study of this type is that we do not yet know to what extent different species of marine mammal can detect and avoid tidal turbines. Such information can only come from direct observations of animals interacting with real devices. To date the only study of the movements of harbour seals in relation to a functioning tidal turbine was conducted in Strangford Narrows, Northern Ireland. In that case there was some indication that seals transited less frequently during periods of turbine operation. The spatial resolution of the data was not sufficient to determine whether seals made fine scale avoidance manoeuvres (Keenan et al. 2011). The seals tracked in the present study were not reacting to any form of device. It is therefore not known whether

the observed transit rates through the channel will be indicative of their behaviour in the presence of operating devices. This study therefore does not provide any information to allow us to directly estimate the likelihood that seals will collide with devices, only the likelihood that animals might be in the vicinity of and therefore have the potential to interact with devices.

- Future work planned for summer 2013, as part of the NERC/Defra funded RESPONSE project, will include use of higher temporal resolution GPS tags on harbour seals caught at the same haulout sites in Kylerhea. This data should allow us to further refine the description of diving behaviour and movement patterns.

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