Scientific Advice on Matters Related to the Management of Seal Populations: 2011

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Scientific advice

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

Formal advice is given annually based on the latest scientific information provided to SCOS by the Sea Mammal Research Unit (SMRU), a NERC Collaborative Centre at the University of St Andrews. 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 2011. 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. An update on the financial status of the research program that supports SCOS will be presented to the 2011 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 (*Halichoerus grypus*)
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, haddock, whiting, ling), and flatfish (plaice, sole, flounder, dab). 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 they can feed up to several hundred kilometres offshore although most foraging probably occurs within 100km of a haulout site. 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 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 growth is levelling off. The numbers born in the Hebrides have remained approximately constant since 1992 and growth has been levelling off in Orkney and possibly at some colonies in the northern North Sea

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

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.

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.

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.

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 two 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 harbour seal populations around Scotland with declines since 2000 of 66% in Orkney, 50% in Shetland, 36% in the Outer Hebrides, 46% in the Moray Firth and 84% in the Firth of Tay. These declines are not thought to be linked to the 2002 PDV epidemic that seems to have had little effect 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. The Grey Seal (Protection) Act 1914, providing the first legal protection for any mammal in the UK because of a perception that there was a need to protect seals. 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

In the UK seals are protected under the Conservation of Seals Act 1970 (England, Scotland and Wales) and The Wildlife (Northern Ireland) Order 1985. In Scotland, the legislation has been superseded by the new Marine (Scotland) Act 2010. The Wildlife (Northern Ireland) Order is also currently under review.

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. The act allows for specific Conservation Orders to extend the close season to protect vulnerable populations. At present, after consultation with NERC, three such orders have been 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 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 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.

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.

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

Current status of British grey seals

- UK grey seal pup production in 2010 was estimated to be 50,174
- Pup production remains stable in the Inner and Outer Hebrides.
- Pup production increased by 6% in Orkney in 2010 and continues to increase rapidly in the North Sea
- An independent estimate of population size allows us to select between competing population estimation models and suggests that pup survival is the main density-dependent factor responsible for the levelling off of the pup production trajectory.
- Total UK grey seal population at the start of the 2010 breeding season is estimated to have been 111,300 (95% CI 90,100-137,700)

Variation in the number of pups born in a seal population can be used as an indicator of change in the size of the population and with sufficient understanding of population dynamics may allow estimation of total numbers of seals. Each year, SMRU conducts aerial surveys of the major grey seal breeding colonies in Britain to determine the number of pups born (pup production). The annually surveyed sites account for approximately 90% of all grey seal pups born throughout Britain. The remaining sites producing around 10% of the pups are surveyed less frequently. The total number of seals associated with the regularly surveyed sites is estimated by applying a population model to the estimates of pup production. Estimates of the total number of seals at other breeding colonies that are surveyed less frequently are then added in to give an estimate of the total British grey seal population. Further details are given in SCOS-BP 11/1 and SCOS-BP 11/2.

Pup production

The total number of pups born in 2010 at all annually surveyed colonies was estimated to be 44,874. Regional estimates were 3,391 in the Inner Hebrides, 12,857 in the Outer Hebrides, 20,312 in Orkney and 8,314 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.

1.1 Trends in pup production

Overall, 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 and pup production has been relatively constant since 2004. Overall pup production at colonies in the North Sea continues to increase exponentially, although the increase has apparently slowed at the Isle of May and Farne Islands and the increase is mainly due to 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 never 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. Due to technical problems in 2009, the 2008 production estimates were used for the Inner Hebrides and part of the Outer Hebrides in last year's reports. This may have masked the real changes between years. Over the two year period from 2008 to 2010 the pup production estimate at annually monitored colonies increased by an average of 4% p.a.

The 2010 pup production estimates for the Inner and Outer Hebrides are effectively the same as the 2008 estimates (changes of 0 and 0.5% p.a. respectively) The Orkney estimate in 2010 was 6.1% higher than in 2009 and the North Sea colonies continued their rapid increase, with an overall increase of 8.8% between 2009 and 2010.

On a longer timescale, during the most recent 5-year period (2005-2010) the total pup production for all annually monitored colonies in the Inner and Outer Hebrides has remained almost constant and Orkney pup production has grown slowly. However, as previously reported, pup production at colonies in the North Sea continued to increase at around 10% p.a. over the same 5 year period. 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 11/1). 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	2,566	+14.4%	+15.0%
Farne Islands	1,499	+11.4%	+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

1.2 Population size

Because pup production is used to estimate the total size of the grey seal population, the estimate of total population alive at the start of the breeding season depends critically on the factors responsible for the recent deceleration in pup production.

Pup production can be used to estimate total population size with appropriate estimates of pup and non pup survival and age-specific fecundity rates. Until the late 1990s the population 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.

The recent levelling off in pup production in the Northern and Western Isles is the result of 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). 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). However, additional information is now available 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). This estimate is assumed to represent the total population of grey seals just before the 2008 breeding season. In 2010 we reported the results of an initial fitting process where two Bayesian state-space models of grey seal population dynamics were fitted to the English and Scottish regional estimates of pup production from 1984 to 2009 (SCOS-BP 10/2), and to the independent estimate of total population size just before the 2008 breeding season.

Incorporating the independent estimate of population size influenced estimates of population size for the entire time series in both models. The posterior model probabilities were 1.0 for a model incorporating a density-dependent pup survival factor (in previous reports referred to as EDDSNM this will in future be referred to as the pup survival model) and 0.0 for a model incorporating a density-dependent fecundity factor (in previous reports referred to as EDDFNM this will in future be referred to as the fecundity model). As a result of the weighting, the model-averaged estimate of total population size was identical to that for the pup survival model. Therefore, only the pup survival model has been used this year.

History of model fitting process.

Until 2007 SCOS presented the lower estimate resulting from the model assuming density dependence in pup survival. This was seen as the conservative estimate of the total grey seal population. However, we used the combined confidence limits of both models to reflect the degree of confidence in the population estimate. In 2008 and 2009 SCOS presented model weighted average estimates of the population to better represent the level of uncertainty in model selection. As the models had similar weights the resulting estimates were equal to the averages of the two model estimates and the resulting estimates were higher than previously published. In 2010 the inclusion of an independent population estimate changed the relative weightings such that the model weighted average was identical to the density dependent pup survival model estimate.

Two model estimates were fitted to the regional pup production estimates for 1984 to 2010, one with the independent population estimate and one without. In the absence of other information to the contrary it seems sensible to accept the model fit that incorporates all the available information.

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 is 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 thepup 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 (approx C.I. 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 0.6% 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 less than 1% p.a. since 2000. The North Sea population has increased at around 4% p.a. since 2000.

The population estimate for the annually monitored sites in 2009 published in the 2010 SCOS report was 119,400 (95% CI 92,500-156,200) based on a preliminary analysis of the independent population estimate. The independent estimate was later revised and the model fitting exercise was repeated producing a lower population estimate. A revised version of the SCOS BP 10/2 is appended to the 2010 report.

The independent population estimate increases our ability to discriminate between the models and means that the problem of model selection has been effectively overcome. This and a programme of continually updating the independent estimate means that such changes in treatment of model outputs are unlikely to be repeated. SCOS emphasizes the importance of this independent estimate for answering these crucial questions. In addition to resolving the model selection problems, the independent estimate has dramatically reduced the magnitude of the confidence intervals around the mean estimate.

In 2008 and 2009 SCOS recommended that additional studies to obtain independent estimates of population size, fecundity and both pup and adult survival should be given high priority. SCOS discussed and approved a series of studies to provide additional insight into the dynamics of the grey seal population:

- A detailed analysis of the haulout behaviour of a large sample of grey seals determined by satellite telemetry was reviewed. Results indicate that approximately 35% of the grey seal population is hauled out at the time of the annual harbour seal surveys and that there are no significant regional, sex or age differences in haulout probability. These data have been reanalysed and a revised estimate with tighter confidence intervals has been used in the model fitting process. The revised analysis and a revised version of the 2010 population assessment paper are presented as SCOS BP 10/2 and 11/6. The resulting independent population estimate was 88,300 (95% confidence interval: 75,400 – 105,700). This estimate was significantly higher than the published estimate used last year, but because it had tighter confidence intervals the overall effect on the model fitting procedure was to produce a slightly lower fitted population size. This revised independent estimate has been used in the fitting the pup-survival model to the data for 1984 to 2010 (SCOS BP 11/2).
- A preliminary analysis of temporal patterns of variability in haulout behaviour was carried out to assess potential bias in the independent population estimate arising

from non-random sampling of seals for the telemetry studies. Initial results indicate that although there are significant correlations between haulout behaviour of individuals over short time periods, these relationships are no longer significant over periods of more than six weeks. It is therefore highly unlikely that the haulout behaviour of seals during the August survey window is correlated with their behaviour at the time of capture. This implies that haulout probabilities in August, and therefore also the independent population estimate are unlikely to have been biased by differences in capture probabilities at the time of tagging.

- A preliminary version of a complementary modelling approach was presented in SCOS BP 10/5. A simple Bayesian method, using generalised additive models to smooth a series of pup production estimates followed by matrix models to scale their results up, was used to estimate the trajectories of four British grey seal populations. A uniform prior on the relative importance of density dependence in fecundity and first year survival is applied to produce an overall estimate and credibility (Bayesian confidence) interval for each population. This approach requires fewer assumptions than the current State Space Models while producing similar population estimates and credibility intervals. A revised version of the 2010 BP has been submitted for publication.
- SMRU have continued the analysis of data from the long-term studies on the Isle of May and North Rona to extract information on fecundity, age at first reproduction and adult survival and the effects of co-variates on population parameters. SCOS recommends that the studies to improve priors on demographic parameters should be encouraged. A summary of the outputs from the long term reproductive biology study on North Rona and an analysis of the effects of changes in individuals pupping dates with age on colony average pupping date were discussed by SCOS and will be the focus of a scientific review during SCOS 2012.
- An extensive program of methodology development and data extraction from pelage photographs of seals on the breeding beach has been established. A preliminary report on developments was discussed and will form part of the review in SCOS 2012.

In light of the improvements in model fitting provided by the independent non breeding season estimate, the level of uncertainty in the population estimates associated with the relationship between numbers of pups and adults has been greatly reduced. However, there are also uncertainties associated with the estimates of pup production, which were believed to lie within a range of –10% to +13% of the values provided. Since 2006 the model used to generate total population estimates provides an independent estimate of the measurement errors in pup production estimates. The fitted estimate of the CV of the pup production estimates was 8.3% (95% credibility interval 6.8-10.1%). There are additional unknown uncertainties associated with the estimates of pup production at colonies that are not surveyed annually.

There are also uncertainties about the value used for adult male survival, about which little is known. This may now represent the main source of uncertainty in the grey seal population estimation process

1.3 Population Trends

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. Pup production in Orkney also appears to have levelled off since the end of the 1990 (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. 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.

1.4 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	400	2008	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	**10,000**		**Increasing**
Canada - Sable Island	62,000	2008	Increasing[4]
Canada - Gulf St Lawrence + Eastern Shore	14,400	2007	Declining[6]
USA	2,600	2008	Increasing[7]
WORLD TOTAL	**137,700**		**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] Bowen, W.D., McMillan,J.I. & Blanchard, W. 2007. Reduced Population Growth Of Gray Seals At Sable Island: Evidence From Pup Production And Age Of Primiparity. Marine Mammal Science, 23(1): 48–64

[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. 2007 Estimated size of the Northwest Atlantic grey seal population 1977-2007 Canadian Science Advisory Secretariat: Research Document 2007/082 pp31.

[7]NOAA (2009) http://www.nefsc.noaa.gov/publications/tm/tm219/184_GRSE.pdf

Current status of British harbour seals

- Approximately 25,950 harbour seals were counted in the U.K. giving an estimated total population of 36,050:
    - 79% in Scotland; 16% in England; 5% in Northern Ireland
- Compared with the mid 1990s, some populations have declined by:
    - 50% in Shetland; 68% in Orkney; 35% in the Outer Hebrides; and 85% 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,
- The 2010 English East coast counts were 5% higher than in 2009 and are 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 11/3. It was considered to be impractical to survey the whole coastline every year and SMRU aimed 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 time of year, state of the tide and 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 (2007-2010) at all sites, approximately 25,950 harbour seals were counted in the U.K: 79% in Scotland; 16% in England; 5% in Northern Ireland (Table 3). Including the 2,900 seals counted in the Republic of Ireland produces a total count of 28,850 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 (SCOS BP 11/8). The result is similar to previously derived estimates and suggests that approximately 72% (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 population of harbour seals in the UK in 2010 was 36,050 (approximate CI 29,500 – 48,050).

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

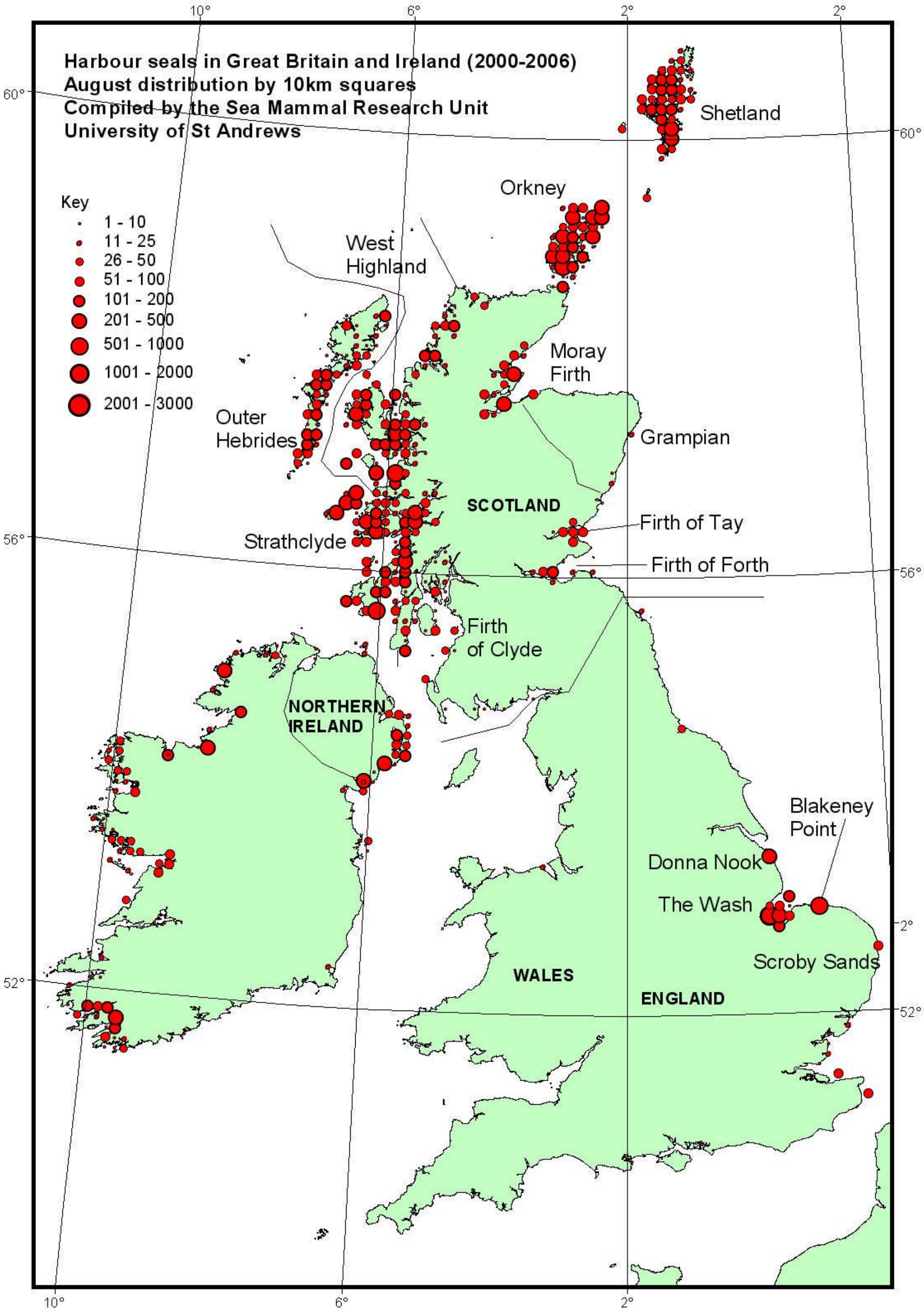
UK population was even less pronounced. However, again the English east coast populations were most affected. Counts since 2002 did not indicate a recovery in The Wash population following the epidemic until 2009 when a large increase was observed. This increase continued in 2010. Similar large increases in pup production were observed in the Wash in 2009 and 2010 (SCOS BP 11/3 & 11/4).

Table 3 Counts of harbour seals by region

Harbour seal Management Area	**Recent count** (2007-2010)	**Previous count** (2000-2005)	**Earlier count** (1996-1997)
Shetland	**3,003** 2009	**4,883** 2001	**5,991** 1997
Orkney	**2,688** 2010	**7,752** 2001	**8,523** 1997
Highland North coast	**112** 2008	**174** 2005	**265** 1997
Outer Hebrides	**1,804** 2008	**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)	**5,834** 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	**241** 2007, 2010	**406** 2005	**648** 1997
East Scotland, Moray Firth (widest) Fraserburgh to Duncansby Head	**1,114** 2007, 2010	**959** 2005	**1429** 1997
TOTAL SCOTLAND	**20,474**	**28,812**	**29,532**
	(2010)	(2005)	(1997)
Blakeney Point	**391**	**709**	**311**
The Wash	**3,086**	**1,946**	**2,461**
Donna Nook	**176**	**421**	**251**
Scroby Sands	**201**	**57** 2004	**65**
Other east coast sites	347	**153** **1994-2003**	**137** 1994 –1997
South and west England (estimated)	**20**	**20**	**15**
TOTAL ENGLAND	**4,221**	**3,306**	**3,240**
TOTAL BRITAIN	**24,695**	**32,118**	**32,772**
TOTAL NORTHERN IRELAND	**1,248** 2002	**1,248** 2002	
TOTAL BRITAIN & N. IRELAND	**25,943**	**33,366**	
TOTALREPUBLIC OF IRELAND	**2,905** 2003	**2,905** 2003	
TOTAL GREAT BRITAIN & IRELAND	**28,848**	**36,271**	

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 2010 are described in more detail in SCOS-BP 11/3 and 11/4. It has not been possible to conduct a synoptic survey of the entire UK coast in any 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.

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 2009



Population trends

As reported in SCOS 2008, 2009 and 2010 there have been general declines in counts of harbour seals in several regions around Scotland.
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.

Counts in the Outer Hebrides in 2008 were 35% lower than the peak count in 1996. Regular surveys over the intervening period suggest that there has been a sustained but gradual decline of around 3% pa since 1996.

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.

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

Surveys of the Scottish east coast populations in 2010 showed contrasting trends (SCOS-BP 11/3), The Firth of Tay count was similar to the 2009 value, but is consistent with variation around a continued rapid decline. This SAC population has declined at an average rate of 20% p.a. since 2002 with the 2010 count 82% lower than the peak count in 2000. In contrast, counts in the Moray Firth showed a large inter-annual increase.

Overall, the combined count for the English East coast population (Donna Nook to Scroby Sands) in 2010 was 5% higher than the 2009 count which was 21% higher than the 2008 count. The 2010 total count was close to the pre epidemic count in 2002 (SCOS-BP 11/3, Figure 10, Table 4). At the same time, the 2010 peak pup count for the Wash was 26% higher than 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 12% between 2008 and 2009 and has grown by approximately 13% pa since the 2002 PDV epidemic.

Response to harbour seal declines

These 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.

1. Is it likely that an artefact of the survey methodology or any of the following changes in the seals' behaviour could account for the observed changes in counts without a population change?
   - Changes in timing of peak counts during the moult
     - *Orkney and west coast moult times similar and consistent with other areas, therefore not a significant factor in declines,*
   - Changes in patterns of haulout behaviour
     - *Orkney and west coast haulout patterns were similar therefore not a significant factor in declines,*
   - Movement, e.g. migration to neighbouring regions
     - *No evidence from any telemetry study of major movements, although pups dispersed between neighbouring regions. Not thought likely to be major factor but cannot be ruled out*

2. Is reduced food availability causing any of the following effects? If so are they sufficient to account for the observed declines through:
   - Reduction in pup survival
     - *pup survival low in Orkney and west coast, but not different between areas.*
   - Reduction in adult survival
     - *no information*
   - Reduction in fecundity
     - *no information*

3. Is the decline due to competition between harbour and grey seals?
   - Do grey and harbour seals compete for food?
     - o *UK wide diet comparison underway. Samples for both species collected and being analysed. Preliminary results in 2012*
   - Do grey seals exclude harbour seals from certain habitats?
     - o *No information. Analysis of existing telemetry data may be useful, but limited simultaneous movement data available*
   - Do grey seals kill young harbour seals?
     - o *Some anecdotal information suggests this may occur in Orkney, the Moray Firth and East Anglia*

4. Are any of the following direct mortality effects having a significant impact on the harbour seal population?
   - Disease
     - o *major effects on UK harbour seal populations have bee documented in 1988 and 2002, but not apparently associated with recent declines*
   - Biotoxins
     - o *Results of monitoring suggest may be a contributory factor around Scotland*
   - Pollution
     - o *Not thought to be a major contributory factor*
   - predation
     - o *predation by killer whales (Orcinus orca) may be a contributory factor in Shetland*
   - By catch

    - *Little information, but 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, 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 and repeat surveys in Orkney,
2. continuation of the annual fixed wing survey 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. completion of analysis of pup survival rates in two populations with contrasting dynamics, i.e. Orkney and the west coast.
6. continued investigations into disease and environmental factors affecting survival in harbour seals

Results from 1 to 5 were presented to SCOS in 2010.

In 2009 a previously unidentified source of anthropogenic mortality was identified in harbour and grey seals in Scotland. Throughout 2010 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. 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 2011 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. 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.

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	1,800	2008	Declining
Scottish W coast	11,400	2007-2009	None detected
Scottish E & N coast	1,600	2010	Declining
Shetland	3,000	2009	Declining
Orkney	2,700	2010	Declining
Scotland	**20,400**		
England	**4,200**	2008	Recent decline[3]
Northern Ireland	**1,200**	2002	Decrease since '70s
UK	**25,900**		
Ireland	2,900	2003	Unknown
Wadden Sea-Germany	10,200	2010	Increasing after 2002 epidemic
Wadden Sea-NL	5,000	2010	Increasing after 2002 epidemic
Wadden Sea-Denmark	2,800	2010	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	**54,400**		
Total	**80,300**		

[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.
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 known about the population structure, including survival and age structure, of grey and harbour seals in European, English and Scottish waters? Is there any evidence of populations or sub-populations specific to local areas?*

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[1,2]. 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[3] and within Scotland, there are significant differences between grey seals breeding on the Isle of May and on North Rona[4]. 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.

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 Inner Hebrides, Outer Hebrides, Orkney and 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), again implying a high degree of philopatry.

The lack of large scale redistribution is supported by the results of detailed studies at breeding colonies and re-sightings of branded and flipper tagged females that indicate that breeding females tend to return to their natal breeding colony and photo-identified individuals that indicate that they then remain faithful to that colony for most of their lives[5].

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 19000 distinct IDs. The current project is focussing on the breeding season photographs from North Rona. Initial results are encouraging and SCOS recommends that this work and further analysis of data from the long term demographic studies be given high priority.

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

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1 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

2 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.

3 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

4 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.

5 Pomeroy, P.P., Twiss, S. & Redman,P. (2000). Philopatry, site fidelity and local kin associations within grey seal breeding colonies. Ethology 106 (10): 899-919

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.

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 independent population estimate (SCOS-BP 10/4) strongly suggests that the density dependent effect is 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.

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 and have previously been presented to SCOS. An analysis of these data has been submitted for publication. 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 (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 IM.

Overall fecundity estimates differed between sites (North Rona =0.63(CI 0.55, 0.69); Isle of May = 0.76(CI 0.72, 0.82)) 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[6].

Both results are consistent with the differing dynamics at these two colonies and suggest that differences in vital rates among colonies may be widespread.

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[6] Boyd, I. L. (1985). "Pregnancy and ovulation rates in grey seals ({IHalichoerus grypus}) on the British coast." Journal of Zoology **205**(A): 265-272.

Harbour seals

Our knowledge of all 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.

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[7] [8]. The Irish-Scottish, the English east coast and the Wadden Sea harbour seals were identified as distinct population units. 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.

In 2010 Scottish Government and Natural England provided additional funding for a study of the degree of genetic differentiation and spatial structure within the UK harbour seal populations. Analysis of samples from 453 harbour seals around the UK and in comparison groups in Europe and California is underway. All the samples have been extracted and a subset genotyped to date. Preliminary results suggest some differentiation between the Wash and the rest of the UK but this and other patterns of population differentiation will be confirmed when the final dataset is analysed.

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[9] 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 temporarily.

Age and sex structure

The absence of any extensive historical cull data or a detailed time series of pup

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7 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.

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

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

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 sampled during other studies since the 1970s, from dead seals sampled during the 1988 PDV epidemic and from a small sample of seals culled in the 1970s. The sample is relatively small and unbalanced reducing the scope for testing for differences. However results do indicate that the live captured animals of both sexes were not different in length pre and post the decline.

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 capture bias may certainly be responsible, it also may 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 (SCOS BP 11/4).

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.

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 are presented in SCOS-BP 11/5

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). 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)

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 was discussed. A version of the paper will be submitted for publication in 2012.

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. However, all areas counted in 2010 showed either no change or in some cases a large increase over the previous count. Details of surveys carried out and the counts obtained are given above in answer to Question 1. Figure 2 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 approximately11% p.a. since 2001. However, the 2010 count was similar to the 2008 count and may indicate 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 declined by approximately 35% since the mid 1990s, indicating a sustained but gradual decline of around 3% pa since 1996.
- the Strathclyde harbour seal population has shown wide fluctuations but recent surveys indicate little overall change since the mid 1990s.
- the population in the Firth of Tay has declined dramatically, by approximately 85% in the last 10 years (Figure 3).
- the counts in the Moray Firth increased by more than 40% between 2009 and 2010. This follows 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.
- 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 9% between 2009 and 2010, following a dramatic 30% increase the previous year. The 2010 count was similar to the pre epidemic count in 2001.
- the nearest European population, in the Wadden Sea, has continue to grow at approximately 13% pa since the 2002 PDV epidemic.

Fig. 2. Trends in moult counts of harbour seals around Scotland.

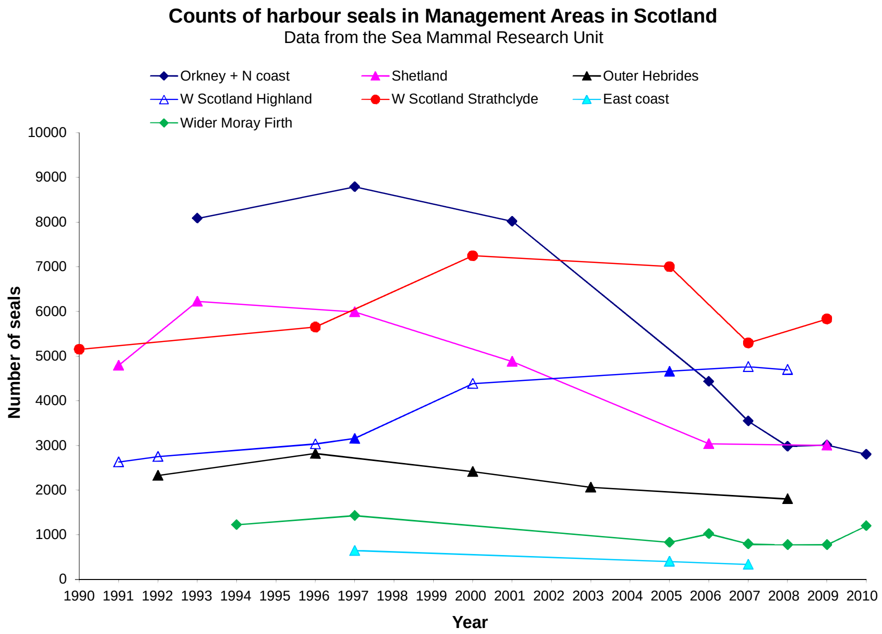
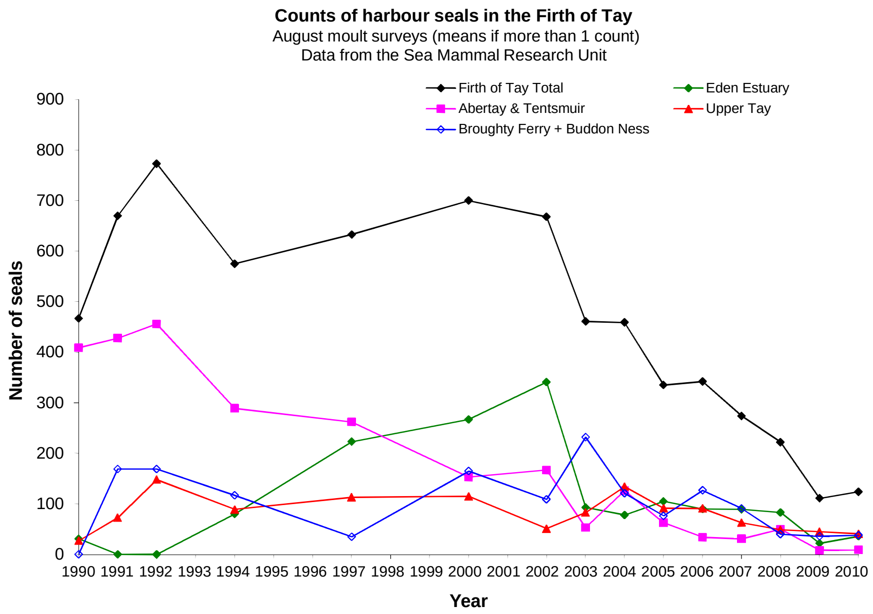


Fig. 3. Trends in moult counts of harbour seals in the Firth of Tay and Eden S.A.C.



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

The continued, dramatic decline in the population of harbour seals in the Firth of Tay and Eden Estuary SAC is a clear cause for concern. 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 is 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.

Conservation orders are currently in place for the 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 has shown 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 has now been extended to the Outer Hebrides.

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.

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

The current state of knowledge with respect to specific hypotheses and/or questions related to the declines are given above in response to Q1 (page 16).

In response to the reported declines, SMRU convened an internal workshop to identify the salient features of the declines and develop a research programme to address the most likely candidate causal factors. The report of the workshop was considered by the Scottish Seals Working Group and a proposed work package was developed. A list of questions to be addressed is presented above (Question 1, page 14).

A preliminary step in the process was to develop a modelling tool to gauge the relative importance of real or perceived trends in demographic rates. The detailed data set of ground and aerial counts at the Moray Firth has been used to estimate local population trends. An update of the modelling work was discussed by SCOS and has been submitted for publication.

In addition, because of the urgency of the problem SMRU implemented six data collection projects and added another urgency project in 2010:

1. An extensive air survey programme, supported by intensive ground observation studies, was carried out in summer 2007 and continued in summer 2008 to identify the geographical extent and confirm the magnitude of the declines around the UK. Results have been presented to SCOS in 2008, 2009, 2010 and recent results are presented in SCOS BP 11/3. These studies have determined the scale and geographical extent of the declines and have been the basis for establishing and maintaining conservation orders.
2. A comparative study of pup mortality patterns in a declining population (Orkney) and a stable population (Lismore) was carried out in 2007. Pre-weaning mortality was negligible in both regions. A model incorporating a normal time to tag failure and independent survival estimates in each region was fitted. Survival did not follow a simple exponential decay and was best fitted by a gamma distribution that allows for a gradually increasing probability of death, consistent with results in Danish seals that show higher winter mortality. Results indicate that pup mortality was similar in the two samples and was therefore not identified as the main determinant of differences in observed population dynamics between Orkney and Lismore populations. However, this is based on a single year's pups and repetition of the pup survival study would be valuable in confirming this.
3. Archived blood samples from grey and harbour seals were screened to assess prevalence of anti-leptospira, toxoplasma and phocine distempter virus antibodies over the period 1991-2005. The results suggested it is unlikely that these infections played a major role in the decline of Scottish harbour seals (SCOS-BP 08/6). A follow-up comparative study of declining and stable populations was carried out between August and October, 2008. There was no evidence, in our sample of captured animals, of differences in levels of acute disease, no signs of infection, no abnormal parasite infestations, no evidence of a recurrence of PDV infections and no signs of nutritional stress. Thus ruling these out as possible causes for the decline. Detailed results were presented in SCOS BP 09/6.
4. One factor of interest is the potential role that biotoxins produced by various species of harmful algae might play (SCOS BP 10/10). These so-called harmful algal blooms or HABS are now part of the natural phytoplankton flora of the coastal seas around Scotland during the spring and summer months. The biotoxins they sometimes produce are well known to cause serious and sometimes fatal diseases in humans and wildlife when consumed through contaminated shellfish (diseases known as amnesic, diarrhetic and paralytic shellfish poisoning). A study funded by Marine Scotland Science, in conjunction with the study on harbour seal diet, was carried out in 2009 and 2010 to determine the extent and routes of exposure. Our results showed that exposure to domoic acid, a neurotoxin produced by diatoms of the genus *Pseudo-nitzschia*, is widespread among harbour seals around Scotland. In some regions, such as Shetland and the southeast coast, the proportion of positive harbour seal faecal samples (indicating animals had been exposed to domoic acid) was ≥70% and these regions are among those where the rate of decline in harbour seals has been highest. However, major declines have also been reported in Orkney and the Outer Hebrides where the proportion of positive samples was lower (30 and 43% respectively). We found that domoic acid is most likely to have been ingested by seals which prey on demersal benthivores such as flatfish and squid, where higher levels of DA were found in the guts of these fish and cephalopods than other species from the same area sampled at the same time. Grey seals appear to be less exposed and this may be due to the differences in the prey preferences and foraging locations between the two seal species. Two stranded harbour porpoise were also found to have been exposed to DA with measureable levels in their faeces or urine. Preliminary results also suggest that harbour seals are also ingesting saxitoxin, a potent biotoxin produced by dinoflagellates from the genus *Alexandrium*, which affects the nervous system and causes paralytic shellfish poisoning in humans. Further risk assessment studies are required to determine the impact such exposure is likely to be having on the health and survival of the Scottish harbour seal and PhD

project in conjunction with Marine Scotland Science in Aberdeen and SAMS, starting in autumn 2011 will continue this work.

5. 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 was carried out in summer 2009. Results are presented in SCOS BP 11/8
6. An on-going study of killer whale behaviour in Shetland has provided an opportunity to estimate predation rates. Results from 2008 & 2009 included direct observations of 4 successful kills and 2 recent kills. Extrapolating from these observations produced estimated takes similar to those based on assumptions about the degree of reliance on seals as prey and energetic requirements. Results suggest that killer whales cannot be ruled out as a contributory factor in the declines (SCOS-BP 10/7).
7. Corkscrew injuries: An additional project was started in 2010 in response to a novel mortality event that has recently been identified in UK seal populations. A summary of the results is given in response to Q13 below and a detailed description of the pathology, distribution and likely causal mechanisms is given in SCOS BP 11/7

6. What evidence is there that would indicate what the limits of the natural variation in population numbers in common seals would be?

This is not a question that could be answered for any wild animal population. There is no information on the maximum or minimum populations of harbour seals in any areas of the UK prior to the recent monitoring programmes.

It appears that the populations of grey seals were very low until the early part of the 20th century. Grey seals are extremely vulnerable to human exploitation and appear to have been almost absent from the North Sea for long periods until the 20th Century and were probably also severely depleted in Orkney and the Hebrides. Harbour seals were much less vulnerable until the invention of accurate fire arms, so it may be that harbour seal populations were relatively large because of uneven human predation pressure. The reduction in human predation pressure on grey seals has allowed their population to recover and spread to areas to areas such as the southern North Sea where they would never have bred successfully in the past. This increase may have direct consequences for harbour seal populations throughout the UK.

Seal Diet

7. What are the current best estimates on seal consumption of salmon and sea trout?

There are no new data on salmon predation by seals in the UK. We do not have sufficient information to allow us to estimate predation on salmonids at a national scale. There are however three separate research projects that do or will provide information on local predation rates.

- Diet studies in the Firth of Tay and St Andrews Bay suggested that seals hauling out inside the estuary were preying on salmon during spring and summer and on sea trout during the autumn. Harbour seal faecal samples from St Andrews Bay outside the Firth of Tay did not contain sea trout and had very few salmon otoliths. Salmonid otoliths appeared in only a few samples, producing very wide confidence intervals on the consumption estimates. The results are therefore of limited value for management purposes. The continued rapid decline of harbour seal populations will have reduced the estimated consumption, but the proportions of the local harbour seal population hauling out in the Firth of Tay and St Andrews Bay have also changed from approximately 30%:70% before 2003 to 55%:45% since 2003 [10].

- Observations of seals consuming salmonids in rivers during regular surveys between 2005 and 2008 allow estimation of total consumption by month. Fish can not usually be identified to species level so figures are given for salmonids. Numbers of fish consumed peaked in winter in all three rivers, thought to be the result of targeted predation on kelts[11]. Additional data on kelt predation were collected in the river Kyle in winter 2010.
- A research program in Shieldaig to directly monitor predation by harbour seals on sea trout smolts using PIT tags and a purpose built seal-borne recorder and transmitter system continued in 2010/2011. Three seals were caught and fitted with loggers. One pit tag was fed to each to confirm the correct operation of the system. A total of 140 days of data were received from the 3 seals. No additional pit tags were detected implying that no tagged smolts were consumed by the study animals

Seals and Salmon Netting Stations

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 initiated at netting stations in both the Moray Firth and the Angus coast south of Montrose. Photo-identification of the seals showed that 10 grey seals and 4 harbour seals were identified, that the majority of these were identified on one occasion, and that 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. A full analysis of the results will be presented to SCOS 2012.

Available mitigation methods that provide alternatives to shooting include use of Acoustic Deterrent Devices (ADD). During 2009 and 2010 an ADDwas tested at a fixed salmon net. During periods when the ADD was switched *on*, significantly fewer seals observed and significantly more fish were landed per hour than when the ADD was switched *off*. There was evidence that the higher fish landings when the ADD was operating were a direct result of the reduction in the number of seals in the vicinity of the net and the amount of time that seals spent in the area. Fish remains were only found within the net during *off* treatments. Overall, the ADD was found to be an effective seal deterrent. Further modifications to nets and how ADDs are deployed could increase their effectiveness.

Seals and Fish Farms

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

[10] Sharples, R.J., Arrizabalaga, B. and Hammond, P.S. (2009) Seals, sandeels and salmon; diet of harbpur seals in St Andrews Bay and the Tay estuary, South East Scotland. M.E.P.S. 390:216-276

[11]. Graham, I.M & Harris, R.N. (2010) Investigation of Interactions Between Seals and Salmon in Freshwater. Final Report to Scottish Government and SNH 102pp (Copies available from the Sea Mammal Research Unit e-mail dt2@st-and.ac.uk)

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 common seals has focussed attention on ways in which it may be possible to reduce unnecessary killing of seals by man.

SMRU have recently completed a study funded by the Scottish Aquaculture Research Forum (S.A.R.F)[12]. 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.

Results show that porpoises generally avoid sources of loud noise but at least some porpoises seem tolerant of the noise of ADDs and are able to forage quite close to such sound sources. This conclusion supports observations made by farm site managers over many years. Previous observations from Canada showing clear cut exclusion in response to ADDs measured shorter term exposures and were not made at fish farm sites so that any potential attractive effects of farms sites would have been missing. The extent to which this degree of exclusion may have significant effects on the foraging success or the conservation status of porpoises remains to be answered.

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. The results of this study will be presented to SCOS 2012.

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.

Seals and Marine Renewables

[12] 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

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.

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 common seals during operation. No change or redistribution for either grey seals or harbour porpoises although sightings rates much lower for these and power to detect change 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. 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.

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 marine renewables in the individual seal management areas around Scotland?

Information on numbers of seals shot under licence will be available for Scotland from 2011 onwards. 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 Q13 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 current state of knowledge is presented in SCOS BP 11/7. A number of severely damaged seal carcasses have washed ashore in eastern Scotland and Eastern England. A total of 14 grey and harbour seals have been found in St Andrews Bay, Tay and Eden Estuaries and Firth of Forth between 2008 and September 2010 and 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. In total 9 juvenile grey seals were recorded in the vicinity of the Isle of May in early December 2010 and 5 adult females and one adult male harbour seal have washed ashore in the Tay and Eden estuaries. 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. 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.

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 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 network, with support from Scottish Government, 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 is 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 Q1 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 Q2 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. Preliminary results will be available for SCOS 2012.

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

See answer to Scottish Government Q2 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. Preliminary results from this study will be presented to SCOS 2012.

The answer to this question also depends on the estimate of the number of seals that forage in English waters. Recent rapid changes in the numbers of grey seals counted in the central and southern North Sea haulouts in England mean that the situation is changing rapidly and it is unclear how foraging effort varies seasonally. A set of alternative scenarios will be presented to the SCOS 2012 meeting for discussion before a definitive answer to this question is produced.

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 recently, but controlling seal populations could potentially be achieved by non-lethal reduction of the birth rate or by excluding seals from sensitive habitats and regions. These sorts of interventions have been attempted on a trial basis, on small scales in the past by the Department of Fisheries and Oceans, Canada. Neither SMRU nor the Department of Fisheries and Oceans, Canada, have carried out any recent research on this issue. Different forms of chemical sterilization are available and some are known to be effective in seals. In the past, the technology for delivering chemicals has been deficient and, while this remains the case, we are aware that progress is being made. Nevertheless, the main uncertainties surround the potential secondary effects of this type of intervention on colony structure, which could have the unintended consequences of stimulating population growth.

Although they are not population level control measure, ADDs may provide alternative solutions to fisheries related problems. Answers to Scottish Government Q8 & Q9 above provide information about current research, funded by Marine Scotland Science, being undertaken to use acoustic deterrent devices (ADDs) to exclude seals from sensitive regions. During 2007 a programme of laboratory and field based tests of aversive sounds specifically designed to act as seal deterrents with minimal impacts on non target species have been conducted. Initial results are promising and may lead to more effective local control.

Trials of the effectiveness of commercially available ADDs for deterring seals from specific areas and as barriers to upstream movement of seals were described in answer to Scottish Government Q8 above

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 detailed description of habitat preference modelling based on grey seals in the North Sea has recently been published[13]. 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.

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 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. Results of this study will be presented to SCOS 2012.

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 2010.

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

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.

The discovery of 9 dead adult common seals in St Andrews Bay in June/early July of 2008 was an unusual event, but the pathology was unclear and no further disease related mortality has been observed.

The unidentified disease outbreak in Swedish and Danish waters in 2007 has apparently ended and did not extend to the North Sea populations.

A small and localised outbreak of seal pox at the Farne Islands in 2011 appears to have ended.

Reports of larger than usual numbers of dead harbour seal pups in the Wash in 2010 and 2011 have not been explained, but do not appear to indicate any major disease event.

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 Q1 above.

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

See answer to Scottish Government Q1 above.

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

See answer to Scottish Government Q3 above

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?

See answer to Scottish Government Q3 above

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

The most urgent issues are those surrounding the rapid, widespread decline of harbour seal populations around the UK. The pertinent questions and suggested work programs to address them are described above (See answer to Scottish Government Q3 above) and in SCOS BP 08/5. Identifying the causes, determining whether these causes are continuing to operate and determining their geographical extent will all be important research questions for seal management.

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 summer months are likely to become more important in future. 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.

The reduction in size of the confidence intervals around the grey seal population estimate and the identification of pup mortality as the likely mechanism of density dependence means that understanding the patterns and causes of pup mortality is the main requirement for understanding and predicting future trends in grey seal populations.

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 popi=ulation management.

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.

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 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. For harbour seals in England there are frequent recorded movements between the Wash and both the Thames and Donna Nook sites. In addition, there are recorded movements of pups between all English east coast sites and some records of movements between the Wadden Sea and the English east coast.

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. . A small amount of 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. Sample collection has begun and initial results will be reported to SCOS 2012

Additional laboratory based feeding trials will be required to estimate biases due to otoliths digestion and differential otoliths recovery rates. After the results of this study have been analysed, consideration should be given to a structured smaller scale continuous monitoring programme.

In order to use basic seal diet and consumption 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. Preliminary results were discussed at SCOS 2011 and a complete analysis will be presented to SCOS 2012.

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

See answer to Scottish Government Q7 above.

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?

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 harboue 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

Results of surveys conducted in the Wash in 2010 are reported in SCOS-BP 11/3 and described briefly in answer to Scottish Government Q1 & Q3. Two counts were obtained in 2010. The later survey (14/08/11) counted 55% more seals than the earlier survey (8/08/11) and there were indications that there had been extensive boat activity before the earlier survey. This count has therefore been ignored. The 2010 count in the Wash was 3,086 and represented an increase of approximately 9% over the mean 2009 count**.** The peak count of pups in the Wash was 26% higher than the 2009 count and 44% higher than the 2008 peak count.

Overall, the combined count for the English East coast population (Donna Nook to Scroby Sands) in 2010 was 5% higher than the 2009 count which was 21% higher than the 2008 count. The 2010 total count was close to the pre epidemic count in 2002 (SCOS BP 11/3, Figure 10, Table 4). Despite these recent 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 12% between 2008 and 2009 and has grown by approximately 13% pa since the 2002 PDV epidemic.

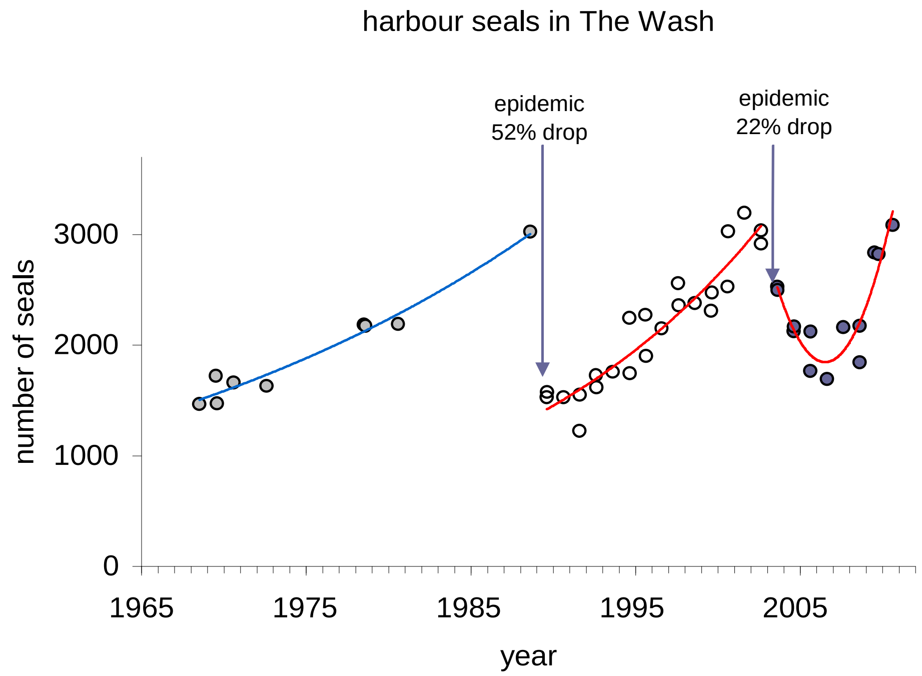


Figure 4. Counts of harbour seals in The Wash in August, 1967 - 2010. These data are an index of the population size through time. Fitted lines are exponential growth curves (growth rates given in text) with a 2nd order polynomial for post-2002 counts for illustration.

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 are 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 5). 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.

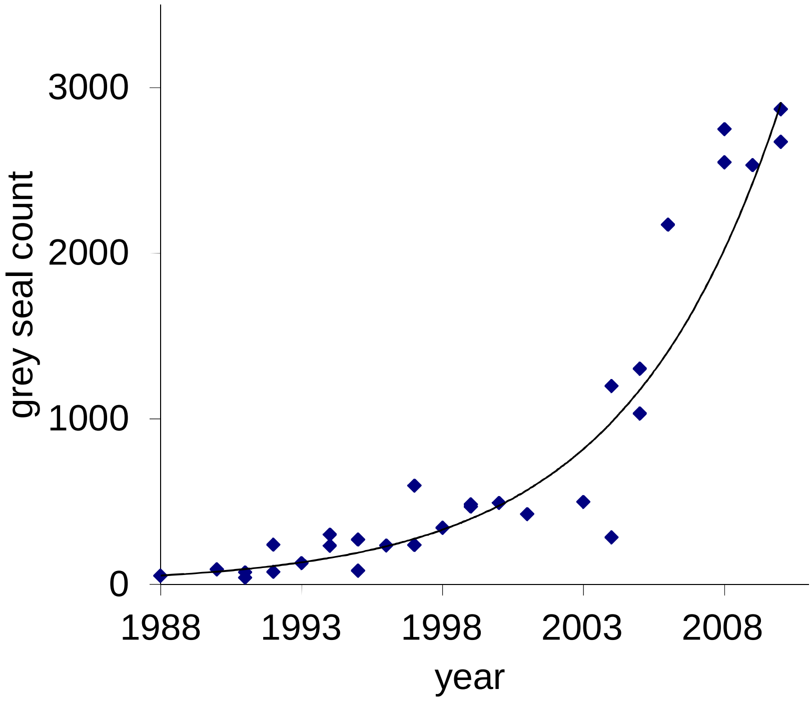


Figure 5. Counts of grey seals hauled out in Lincolnshire, Norfolk and Suffolk during August over the period 1988 - 2010. Fitted line is an exponential curve with an annual rate of increase of 18% (R^2 = 0.87).

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 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 of some sort. At present the reasons for the lag in recovery However, the rapid increase in foraging effort by grey seals in the region may be 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 Q8 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 Q9 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 Q7 & Q8 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 fresh water are underway, funded by Scottish Government. These are described briefly in answer to Scottish Government Q8 & Q9 above.

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

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 are described briefly in answer to Scottish Government Q7 above.

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

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'?

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

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?

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. This is the first year of operation of the Marine Scotland Act and returns of seal licences will be available to SCOS 2012. Summary information from the initial 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)

The experimental use of ADDs at both salmon farms and on salmon bag nets is described in answer to Scottish Government Qs 8 and 9 above 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 2012 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.

This is impossible to answer. The Scottish code of practice sets a range of 150 metres as the maximum allowable range for shooting at seals. Shooting from unstable/ unsuitable platforms is illegal.

Marine Scotland have established a programme of training for marksmen as part of the new licencing system in Scotland. SCOS strongly recommends that anyone using firearms to kill seals should attend such a course before proceeding. The level of training required will depend on the shooter's innate abilities. Shooting from unstable platforms and long range will dramatically reduce the likelihood of hitting a vital target and will obviously reduce the likelihood of a clean kill.

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

No. 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 seals 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?

Large amounts of research are underway in the UK and throughout the world. Telemetry based studies of movements and behaviour in the areas of high tidal and wave energy have recently been funded by both Scottish and Welsh Assembly Governments. Similar detailed telemetry and population survey studies have been conducted with funding from both public and industry bodies in Scotland and Northern Ireland with the specific aim of investigating fine scale movements in relation to tidal energy devices to inform collision risk models. Research into collision risk models is being conducted by Scottish Association of Marine Science. Scottish and Welsh Assembly Governments have funded baseline studies of grey seal pup movements in high tidal flow areas. Pups were tagged in November and December 2010 to specifically address this topic. An analysis of these data will be presented to SCOS in 2012.

Background/baseline information studies of movements and population status and distribution of both species have been carried out throughout the UK as part of the SEA process with funding from DECC (previously DTI)

SMRU in partnership with Scottish Association for Marine Sciences, CEFAS, Marine Scotland and the Universities of Edinburgh, Aberdeen, Loughborough, Exeter and Cranfield have obtained funding for two consortium grants from NERC and Defra to investigate fine scale interactions between marine mammals and wave and tidal energy generators.

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)

All marine renewable energy projects have to meet assessment requirements of the national/local permitting process. These usually require an extensive environmental impact assessment that should include 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.

Pile driving is the loudest man made sound source in UK waters. Its use will expand and intensify as offshore wind farm developments accelerate. Developing standardised guidelines for mitigation of pile driving noise should be considered a priority.

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 new 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 quickly to 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 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 of grey and common 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.

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 J Armstrong,	Fisheries Research Services;
Dr A.J.Hall,	University of St Andrews;
Dr S Wanless	N.E.R.C. C.E.H, Edinburgh;
Dr J. Greenwood,	CREEM, University of St Andrews;
Professor J. Pemberton,	University of Edinburgh;
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 E.Bradbury (Secretary),	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, 2011

11/01 Grey seal pup production in Britain in 2010
C.D. Duck & C.D. Morris

11/02 Estimating the size of the UK grey seal population between 1984 and 2010, and related research.
L. Thomas

11/03 The Status of British Harbour Seal Populations in 2010
C.D. Duck, C.D. Morris, D. Thompson & D. Malone

11/04 Distribution and abundance of harbour seals (Phoca vitulina) during the breeding season in the Wash. 2001 to 2010.
D. Thompson

11/05 Individual-based approaches to understanding harbour seal population dynamics
L. Cordes and P.M.Thompson

11/06 An estimate of the size of the British grey seal population based on summer haulout counts and telemetry data.
M. Lonergan, B. McConnell, C. Duck & D. Thompson

11/07 Report on recent seal mortalities in UK waters caused by extensive lacerations: October 2010.
D.Thompson, S. Bexton, A. Brownlow, D. Wood, A, Patterson, K. Pye,
M. Lonergan and R. Milne

11/08 Harbour seal (*Phoca vitulina*) abundance has declined in Orkney: an assessment based on using ARGOS flipper tags to estimate the proportion of animals ashore during aerial surveys in the moult
M. Lonergan, C.Duck, C.Morris & D. Thompson.

C.D. Duck and C.D. Morris

Grey seal pup production in Britain in 2010

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

Summary

Between September and December 2010, repeat aerial surveys of approximately 60 grey seal breeding colonies in Scotland were carried out by SMRU. Staff from Scottish Natural Heritage (SNH), National Trust, Lincolnshire Wildlife Trust and Natural England ground counted pups born at colonies in Shetland, Orkney (South Ronaldsay),the Farne Islands, Donna Nook, Blakeney Point and Horsey (East Norfolk).

The total number of pups born at annually monitored colonies in 2010 was estimated to be **44,874,**an increase of **6.10%**compared with the 2009 total of **42,296**.This is the biggest successive year increase since 2003 (7.4% increase from 2002).

The annually monitored colonies account for approximately 90% of grey seal pups born in the UK. A number of colonies are monitored less frequently for a number of reasons including difficulty of access (Wales, SW England) and the relatively small numbers of pups born (Table 2).

1. Surveys conducted in 2010

The locations of the main grey seal breeding colonies in the UK are shown in Figure 1. Each year SMRU conducts aerial surveys of the major grey seal breeding colonies in Scotland to determine the number of pups born. The only unusual event during the 2010 grey seal breeding season survey was heavy and prolonged snow falling at the end of November which disrupted the final survey of breeding colonies in Orkney. Most airports in Scotland were closed and the survey attempt had to be abandoned to ensure safe return to Dundee. This meant the last survey of the later Orkney colonies was missed.

Despite this setback, all colonies were surveyed either four or five times, allowing production estimates to be calculated. Four smaller colonies were surveyed only three times.

A small number of colonies are monitored annually by different organisations: National Trust staff count pups born at the Farne Islands (Northumberland) and at Blakeney Point (Norfolk), staff from the Lincolnshire Wildlife Trust count pups born at Donna Nook and staff from English Nature count pups born at Horsey, on the east Norfolk coast. Scottish Natural Heritage (SNH) staff coordinated a fifth survey of grey seal pups born in Shetland and SNH Orkney staff ground counted pups born on South Ronaldsay.

2. Estimated pup production

Numbers of pups born (pup production) at the regularly surveyed colonies is estimated each year from counts derived from the aerial photographs using a model of the birth process and the development of pups. The method used to obtain pup production estimates in 2010was similar to that used in previous years. A lognormal distribution was fitted to colonies surveyed four or more times and a normal distribution to colonies surveyed three times.

The 2010 total pup production estimate for the annually monitored colonies was **44,874**, an increase of **6.10%** from 2009 (**42,296**; Table 1). This is the biggest increase since 2003 (7.4% increase from 2002).

The trajectory of pup production with 95% confidence limits at all the major breeding colonies in England and Scotland (excluding Loch Eriboll, Helmsdale and Shetland) between 1984 and 2010 is shown in Figure 2a. Figure 2b shows the long-term pup production trajectories at the main island groups from 1960 to 2010. Pup production from the main island groups since 1987 is shown in more detail (including 95% confidence intervals) in Figures 3a (Inner and Outer Hebrides and Orkney) and 3b (North

Sea colonies). The time series of production estimates for the four regional island groups is given in Table 3.

For colonies not surveyed by air, pups were counted directly from the ground. Ground counts are conducted annually at the Farne Islands, Donna Nook, Blakeney Point, Horsey and South Ronaldsay in Orkney but less frequently in SW England and Wales due to the inaccessibility of breeding colonies (Figure 3b). SNH staff count pups in Shetland in a manner compatible with counts from aerially surveyed colonies and, for colonies with sufficient counts, production was estimated using the same modelling procedure.

In 2010, as in the two preceding seasons, aerial surveys were carried out from an altitude of 335m rather than the usual 365m (1,100 rather than 1,200 feet).

3. Trends in pup production

The differences in pup production at the main island groups are shown in Table 1. Between 2009 and 2010, total pup production at annually monitored colonies was estimated to have increased by +6.10% overall with the change varying from –0.15% in the Inner Hebrides to +14.35% at Donna Nook, Blakeney Point and Horsey in east England (Figure 3a).

Figures 2a and 2b and Table 1 show that pup production at the annually monitored colonies is stabilising. Over the past five years, the only colonies that showed any significant increase were at the southern end of the North Sea, at Donna Nook, Blakeney Point and at Horsey (Table1). Since 2001, the increase at the Isle of May and Fast Castle was entirely due to the Fast Castle contribution.

Between 1984 and 1996, pup production estimates from annually monitored colonies showed a fairly consistent annual increase, with the notable exception of 1988 (Figures 2 and 3). More recently, there were declines in pup production in 1997 (mainly due to a reduction in the number of pups born in the Outer Hebrides), in 1999 (in all island groups), in 2002 (mainly in the Outer Hebrides) and in 2005 (primarily in the Orkney colonies). In the years following each of these declines, there was a marked increase in production the following year (of 9.5%, 11.5%, 7.4% and 3.9% in 1998, 2000, 2003 and 2006 respectively). The recovery in 2006 was considerably smaller than on previous occasions.

The overall annual percentage change in pup production at each of the main island groups over the past five years (between 2005 and 2010) is shown in Table 1. The overall annual change, for all colonies combined, was +2.87%. Locally, the change varied from –0.09% in the Inner Hebrides to +15.37% at the relatively small colonies of Donna Nook, Blakeney Point and Horsey. Changes for the two preceding five-year intervals, 1995 to 2000 and from 2000 to 2005 are also shown in Table 1. These changes in five-yearly intervals are probably the best indication of the current trends in grey seal pup production.

4. Pup production model assumptions

The model used to estimate pup production from aerial survey counts of whitecoated and moulted pups assumes that the parameters defining the distribution of birth dates are variable from colony to colony and from year to year, but that those defining the time to moult and the time to leave the colony remain constant. The pup production estimates are sensitive to the value used for the latter parameter and there is, therefore, an argument for allowing this parameter to vary between colonies.

Previously (in 2001), we considered the effect of allowing the time-to-leave parameter to vary. However, although the resulting pup production trajectory is slightly lower, the variations in production are consistent between the two methods. The results presented here are consistent with the Advice provided in previous years and incorporate a fixed mean time-to-leave (and a variable standard deviation) derived from studies on the Isle of May.

Similarly, the proportion of white pups misclassified as moulted (or vice versa) can vary. Variation may be counter dependent or may be simply a function of the quality of the aerial photograph, the prevailing light conditions under which the photograph was taken and the orientation in which any pup might be lying. In 2010, as in 2008, there were sufficient counts (minimum of five) to allow the estimation model to select the most appropriate misclassification proportion.

When counts of pups from the ground were used to populate the model, using a higher percentage of correctly classified pups (90%) produced a better fit with lower confidence intervals. This is because individual pups can be observed for longer and the classification is very likely to be more accurate.

5. Confidence limits

Ninety-five percent confidence limits on the pup production estimates were 3.2%of the production estimate for the Inner Hebrides, 2.4% for the Outer Hebrides, 2.4% for Orkney and 3.3% for colonies in the Firth of Forth(Figures 3a and 3b).

6. Pup production at colonies less frequently surveyed

Approximately 10% of all pups are born colonies not surveyed annually (Tables 2 and 4). Confidence intervals cannot be calculated for most of the estimates provided because they represent single counts. Loch Eriboll, Eilean nan Ron (Tongue) and the coast between Duncansby Head and Helmsdale are exceptions. Loch Eriboll and Eilean nan Ron were surveyed three times in 2010 while the Helmsdale colonies were surveyed four times (Table 2). The 95% confidence interval for the production estimate for the Helmsdale colonies was10.3%of the point estimates. Table 2 includes the total count for the colonies listed individually in Table 4(Other colonies). These and other potential breeding locations are surveyed when flying time, weather conditions and other circumstances permit. Table 2 indicates that at least **5,247**pups were born at colonies in the U.K.that are not surveyed annually.

Note that Oronsay Strand is now included with the Inner Hebrides total and Inchkeith is included with the Isle of May and FastCastle total.

Also note that the surveys described here do not account for seals breeding in caves. Small groups of grey seals breed in caves in the Outer Hebrides, along the Sutherland coast, in Orkney and in Shetland.

7. Pup production in Shetland

In Shetland, SNH staff coordinated a team of volunteers who carried out boat and ground counts of a number of breeding colonies.

In 2010, five colonies were counted four times: Uyea, Rona's Voe, Whalsay Skerries, part of Dale of Walls and Mousa. Papa Stour was counted twice and North Fetlar once. This was the first opportunity to obtain repeat counts at Uyea, with acceptable weather coinciding with low tides. The pup production estimate for Shetland (Table 1).

As with previous surveys, the model was run using both a 50% and a 90% moulter classification. The model produced better fits to the counts, with lower confidence intervals, using the 90% classification. These estimates are in Table 5. Moulted pups are more likely to be correctly classified during ground counts because the counters are relatively close to the pups and can assess more accurately whether a pup has fully moulted or not.

The minimum pup production for Shetland in 2010 was **831** pups (Table 1). This figure is a combination of estimates from 2010 (Mousa, Uyea, Whalsay Is., Rona's Voe and Dale of Walls), 2007 (Papa Stour, South Bressay and NE Unst) and from 2004 (S Havra, Fitfull Head and Muckle Roe) and is a combination of modelled estimates, of maximum counts and of the most recent counts from previous surveys. This is likely to be an underestimate of grey seal pup production in Shetland, since a number of colonies were either not surveyed, or were not surveyed in their entirety. The frequently severe weather conditions during the autumn months may limit any potential increase in grey seal pup numbers on the restricted and exposed breeding beaches and caves in Shetland.

8. Grey seal pup production in Ireland

In the 2005 season, there was a major effort to determine the number of grey seal pups born in the Irish Republic, coordinated by Oliver O'Cadhla from the Coastal Monitoring Research Centre in Cork. Pup production was estimated to be 1,574 (O'Cadhla et al., 2007). Including an estimate of 100 pups born in Northern Ireland, this gives a total of just under 1,700 pups born in Ireland.

To complete the production estimate for the whole of the island of Ireland, in 2005 SMRU surveyed the breeding colonies on the east and south coast of Northern Ireland, as an extension of the existing grey seal survey of Scotland. Four surveys were carried out; the first has to be abandoned due to poor visibility. SMRU previously surveyed breeding grey seals in Northern Ireland in 2002.

In addition, the National Trust and the Northern Ireland Environment Agency (formerly the Environment and Heritage Service, Northern Ireland) conduct monthly boat surveys of seals in Strangford Lough. Approximately 40 grey seal pups are born inside Strangford Lough and here, grey seals appear to breed some 3-4 weeks earlier than those breeding on the small islands to the east of the ArdsPeninsula.

Outside Strangford Lough, the main breeding colonies were on the Copeland Islands at the mouth of Belfast Lough and on the North Rocks off the east coast of the southern end of the ArdsPeninsula. In 2005, on the Copeland Islands, the maximum pup count was 16 and on North Rocks the maximum count was 9 pups. These numbers were considerably lower than counts made in 2002 (14 and 26 pups respectively). These surveys suggest that approximately 100 grey seal pups were born in Northern Ireland in 2005 and Table 2 shows this estimated number.

9. Proposed surveys for 2011

In the 2011 breeding season, we propose to limit surveys to North Sea colonies and to searching for possible new colonies around Scotland.

10. Acknowledgements

We are grateful to all those who helped collect or provided the data presented in this report. These include: John Walton and colleagues (National Trust, Farne Islands), Rob Lidstone-Scott (Lincolnshire Wildlife Trust, Donna Nook), David Wood (National Trust, Blakeney Point), Ron Morris and Bill Bruce (Forth Seabird Group, Forth inner islands). SNH Orkney and Shetland and volunteers for their 2010 grey seal pup survey data. We are grateful to Bill Gilesand Gordon Smith who, once again, enthusiastically and expertly piloted the grey seal survey aircraft.

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Table 1. Pup production estimates for colonies in the main island groups surveyed in 2010. The overall average annual changes, over successive 5-year intervals are also shown. These annual changes represent the exponential rate of change in pup production. The total for the North Sea represents the combined production estimates for the Isle of May, Fast Castle and Inchkeith in the Firth of Forth and for the Farne Islands, Donna Nook, Blakeney Point and Horsey in east England.

Location	2010 production	2009 production	Overall annual change in pup production			
			From previous year	For previous 15 years, in 5 year intervals		
			2009-2010	1995-2000	2000-2005	2005-2010
Inner Hebrides	**3,391**	**3,396**	-0.15%	+1.1%	++1.0%	+0.0%
Outer Hebrides	**12,857**	**12,113**	+6.14%	-+1.0%	-1.7%	+0.9%
Orkney	**20,312**	**19,150**	+6.07%	+5.6%	+1.6%	+2.9%
Isle of May, FastCastle, Inchkeith	**4,249**	**4,047**	+4.99%	+13.2%	+2.1%	+8.8%
FarneIslands	**1,499**	**1,346**	+11.37%	-0.6%	+1.8%	+5.7%
Donna Nook + Blakeney Pt + Horsey	**2,566**	**2,244**	+14.35%	+13.1%	+15.6%	+15.0%
North Sea (i.e. previous 3 areas)	**8,314**	**7,637**	+8.86%	+9.3%	+3.5%	+10.1%
Total	**44,874**	**42,296**	**+6.10%**	**+3.2%**	+**0.7%**	**+3.1%**

Table 2. Pup production estimates for breeding colonies surveyed less regularly.

Location	Location and year of most recent survey	Pup production
[1]Mainland Scotland	[1]Helmsdale (Duncansby Head to Helmsdale, 2010	1,043
	[1]Loch Eriboll, Eilean nan Ron (Tongue) 2010	557
Other colonies	Various, see Table 4	868
Shetland (Table 5)	2010	831
South-west England	South-west England (incl Lundy),	250 (est.)
Wales	All Wales, 1994-2005	1,650 (est.)
Northern Ireland	2005	100 (approx.)
Total		**5,299**

[1]Loch Eriboll, Eilean nan Ron and Helmsdale are surveyed annually with production estimates derived using the same modelling process as for the main breeding colonies.

Table 3.Estimates of pup production for colonies in the Inner and Outer Hebrides, Orkney and the North Sea, 1960-2010.

YEAR	Inner Hebrides	Outer Hebrides	Orkney	North Sea	Total
1960			2048	1020	
1961		3142	1846	1141	
1962				1118	
1963				1259	
1964			2048	1439	
1965			2191	1404	
1966		3311	2287	1728	7326
1967		3265	2390	1779	7434
1968		3421	2570	1800	7791
1969			2316	1919	
1970		5070	2535	2002	9607
1971			2766	2042	
1972		4933		1617	
1973			2581	1678	
1974		6173	2700	1668	10541
1975		6946	2679	1617	11242
1976		7147	3247	1426	11820
1977			3364	1243	
1978		6243	3778	1162	11183
1979		6670	3971	1620	12261
1980		8026	4476	1617	14119
1981		8086	5064	1531	14681
1982		7763	5241	1637	
1983				1238	

Table 3 continued.

YEAR	Inner Hebrides	Outer Hebrides	Orkney	North Sea	Total
1984	1332	7594	4741	1325	14992
1985	1190	8165	5199	1711	16265
1986	1711	8455	5796	1834	17796
1987	2002	8777	6389	1867	19035
1988	1960	8689	5948	1474	18071
1989	1956	9275	6773	1922	19926
1990	2032	9801	6982	2278	21093
1991	2411	10617	8412	2375	23815
1992	2816	12215	9608	2437	27075
1993	2923	11915	10790	2710	28338
1994	2719	12054	11593	2652	29018
1995	3050	12713	12412	2757	30932
1996	3117	13176	14273[1]	2938	33504[1]
1997	3076	11946	14051	3698	32771
1998	3087	12434[2]	16367	3989	35877[2]
1999	2787	11759	15462	3380	33388
2000	3223	13396	16281	4303	37210
2001	3032[3]	12427	17938	4134	37531[3]
2002	3096	11248	17942[4]	4520[4]	36816[4]
2003	3386	12741[5]	18652[5]	4805[5]	39584[5]
2004	3385	12319	19123[3]	4921	39748
2005	3387	12297[6]	17644[6]	5132	38460
2006	3461	11719	19332	5322	39727
2007	3071	11342	18952	5560	38772
2008	3396	12712	18765[7]	6617	41450
2009	3396[8]	12113[8]	19150	7637[8]	42296
2010	3391	12857	20312	8314	44874

[1]Calf of Flotta included with Orkney total (start in 1996).
[2]Berneray and Fiaray (off Barra) included in the Outer Hebrides total (start in 1998).
[3]Oronsay included with Inner Hebrides (start in 2001).
[4]South Ronaldsay included in the Orkney total;Blakeney Point and Horsey (both Norfolk) included with North Sea(start in 2002).
[5] North Flotta, South Westray, Sule Skerry included with Orkney; Mingulay included with Outer Hebrides (start in 2003)
[6]Pabbay included with Outer Hebrides; Rothiesholm (Stronsay) included with Orkney (start in2005).
[7]New colony on Hoy included with Orkney
[8]2008 production estimates were used as a proxy for all colonies in the Inner Hebridesand for 7 colonies in the Outer Hebrides for which new production estimates could not be derived. Oronsay Strand included with Inner Hebrides; Inchkeith included with North Sea.

Table 4. Scottish grey seal breeding sites that are not surveyed annually and/or have recently been included in the survey programme. Most recent counts are in bold type. New colonies on Soa, off Coll and Sandray, south of Barra are included for the first time.

	Location	Survey method	Last surveyed	Number of pups counted
Inner 2 Hebrides	LochTarbert, Jura	SMRU visual	2003, 2007	10, **4**
	West coast Islay	SMRU visual	1998, every 3-4 years	None seen
	Ross of Mull, south coast	SMRU visual	1998, infrequent	None seen
	Treshnish small islands, incl. Dutchman's Cap	SMRU photo & visual	annual	~**20** in total
	Staffa	SMRU visual	1998, every other year	~**5**
	Little Colonsay, by Ulva	SMRU visual	1998, every 3-4 years	**6**
	Meisgeir, Mull	SMRU visual	1998, every 3-4 years	**1**
	Craig Inish, Tiree	SMRU photo	1998, every 2-3 years	**2**
	Cairns of Coll	SMRU photo	2003, 2007	22, **10**
new	Soa, Coll	SMRU photo	2010	**40**
	Muck	SMRU photo	1998, 2005	36, **18**
	Rum	SNH ground	2005, annual	10-**15**
	Canna	SMRU photo	2002, 2005	54, **25**
	Rona	SMRU visual	1989, infrequent	None seen
	AscribIslands, Skye	SMRU photo	2002, 2005, 2007, 2008	60, 64, 42, **64**
	FladdaChuain, North Skye	SMRU photo	2005, 2007, 2008	73, 43, **129**
	Trodday, NE Skye	SMRU photo	2008new	**55**
	Heisgeir, DubhArtach, Skerryvore	SMRU visual	1995, 1989, infrequent	None None
Outer Hebrides	Sound of Harris islands	SMRU photo	2002, 2005, 2007, 2008	358, 396, (194)[2], **296**
new	Sandray, S of Barra	SMRU photo	2010	**40**
	St Kilda	Warden's reports	Infrequent	Few pups are born
	Shiants	SMRU visual	1998, every other year	None
	Flannans	SMRU visual	1994, every 2-3 years	None
	Bernera, Lewis	SMRU visual	1991, infrequent	None seen
	Summer Isles	SMRU photo	2002, 2003, 2005, 2006, 2007, 2008, 2010	50, 58, 67, 69,25, **73**, 29
	Islands close to Handa	SMRU visual	2002	**10**
	Faraid Head	SMRU visual	1989, infrequent	None seen
	Eilean Hoan, LochEriboll	SMRU visual	1998, annual	None
	RabbitIsland, Tongue	SMRU visual	2002, every other year	None seen
Orkney	Sanday, Point of Spurness	SMRU photo	2002, 2004, 2005, 2006, 2007, 2008, 2010	10, 27,34, 21,8,17, **0**
	Sanday, east and north	SMRU visual	1994, every 2-3 years	None seen
	Papa Stronsay	SMRU visual	1993, every 3-4 years	None seen
	Holm of Papa, Westray	SMRU visual	1993, every 3-4 years	None seen
	North Ronaldsay	SMRU visual	1994, every 2-3 years	None seen
	Eday mainland	SMRU photo	2000, 2002	8, **2**
Others	Firth of Forth islands (Inchkeith&Craigleith now included with Firth of Forth)	SMRU photo, Forth Seabird Group	Infrequent, 1997 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010	<10, 4 86, 72,110, 171,206, 50,34, **53**
Total				**868**

[1]Pup production calculated from four counts

[2] 2005 count used in total as pups were missed in 2007

Table 5. Pup production estimates and maximum pup counts for grey seal colonies in Shetland from 2004 to 2010. Frequent severe gales in 2005 restricted the opportunity to count and probably removed significant numbers of pups from some of the breeding beaches. The estimated pup productions for Uyea in 2005 and 2006 are clearly underestimates as only those breeding on beaches that were visible from the mainland could be counted. These data were provided by SNH staff (assisted by SMRU in 2004) and by a team of hardy volunteers. Numbers in italics are maximum counts.

Shetland colony	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
	Estprod'n	**Estprod'n**	**Estprod'n**	**Estprod'n**	**Estprod'n**	**Estprod'n**	**Estprod'n**
Papa Stour	196	135	153	168	*107*	*88*	
Dale of Walls	66	43	*18*	*36*	*10*	33	
Muckle Roe	23	no count	no count	no count	no count	no count	
Rona's Voe	106	83	50	57	*45*	82	
Mousa	140	117	156	128	*122*	178	
Fetlar	50	32	*21*	*23*	no count		
WhalseyIslands	*102*	72	77	103	119	95	
South Havra	*4*	no count	no count	no count	no count	no count	
Fitful Head	*18*	no count	no count	no count	no count	no count	
Uyea (N. Mainland)	*238*	122 (part)	114 (part)	101 (part)	*69* (part)	215 (all)	
NE Unst				*3*	no count	no count	
Noss				*2*	no count	no count	
Total max counts	**362**	**260**	**299**	**324**	**324**	**37**	
Modelled total	**581**	**505**	**459**	**479**	**495**	**794**	
Estimated prod'n	**943**	**765**	**758**	**803**	**819**	**831**	

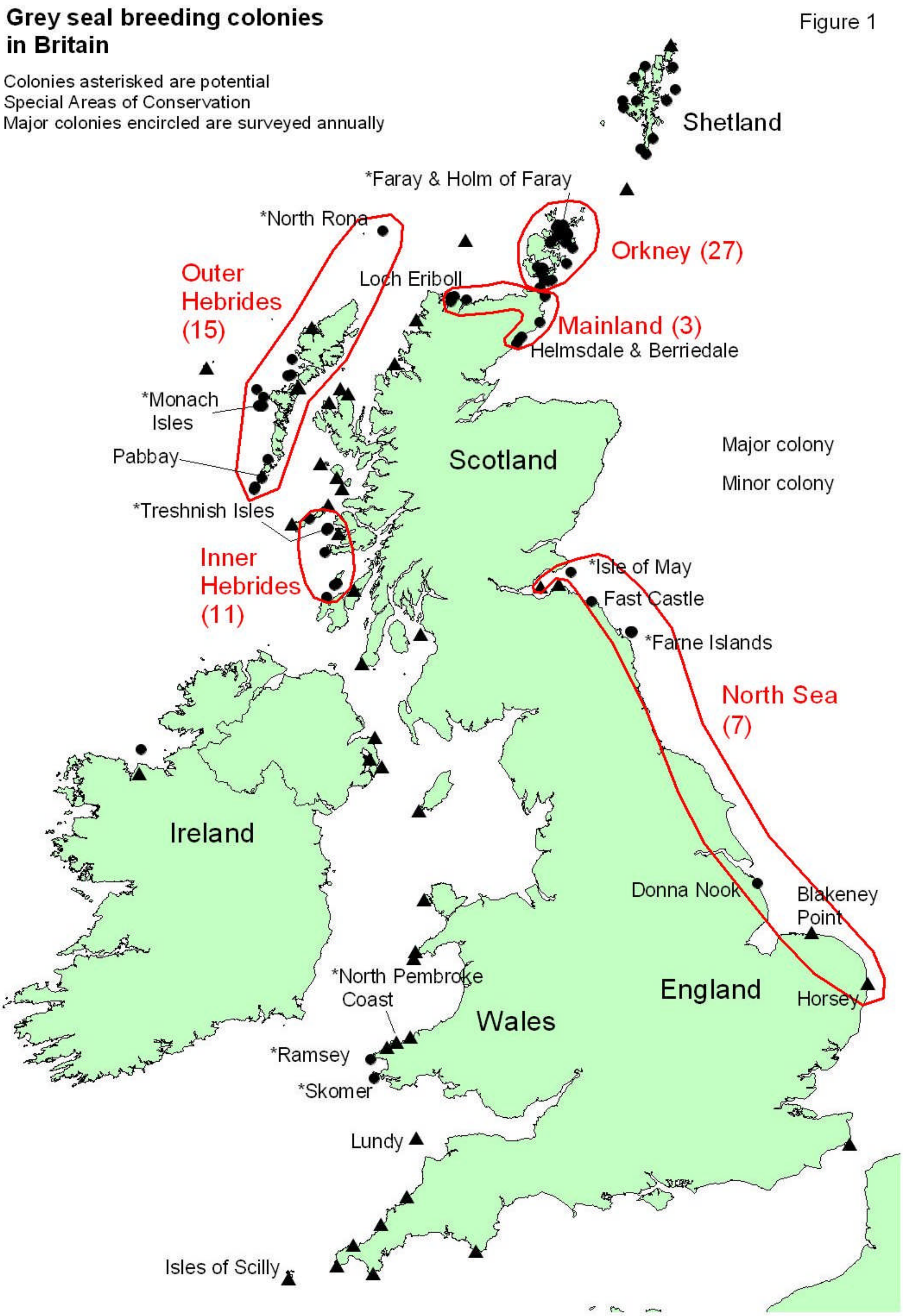

Grey seal breeding colonies
in Britain
Colonies asterisked are potential
Special Areas of Conservation
Major colonies encircled are surveyed annually
Figure 1
Shetland
*Faray & Holm of Faray
*North Rona
Orkney (27)
Outer
Hebrides
(15)
Loch Eriboll
Mainland (3)
Helmsdale & Berriedale
*Monach
Isles
Pabbay
Scotland
Major colony
Minor colony
*Treshnish Isles
Inner
Hebrides
(11)
*Isle of May
Fast Castle
*Farne Islands
North Sea
(7)
Ireland
Donna Nook
Blakeney
Point
*North Pembroke
Coast
England
Horsey
Wales
*Ramsey
*Skomer
Lundy
Isles of Scilly

Figure 2a. Total estimated grey seal pup production, with 95% confidence limits, at all the major, annually monitored colonies in Scotland and England from 1984 to 2010.

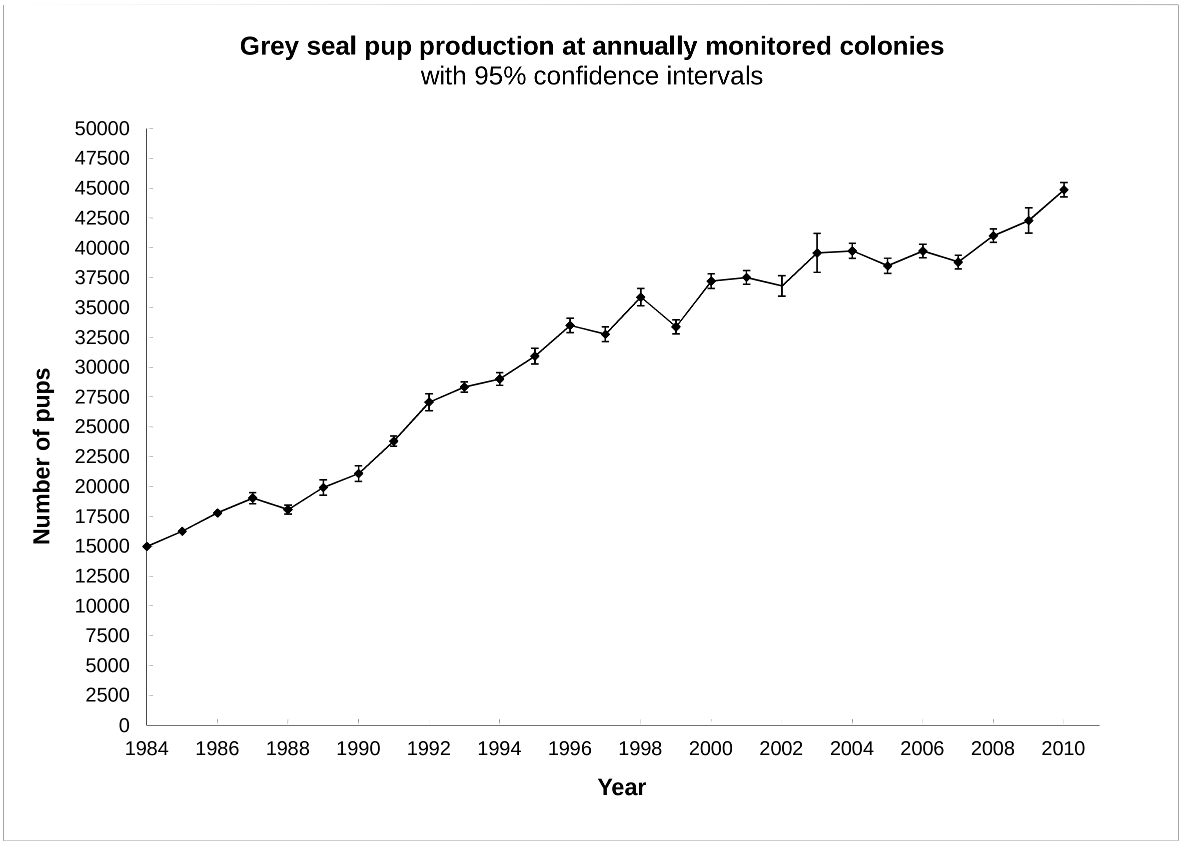


Figure 2b. Grey seal pup production trajectories from 1960 to 2010.

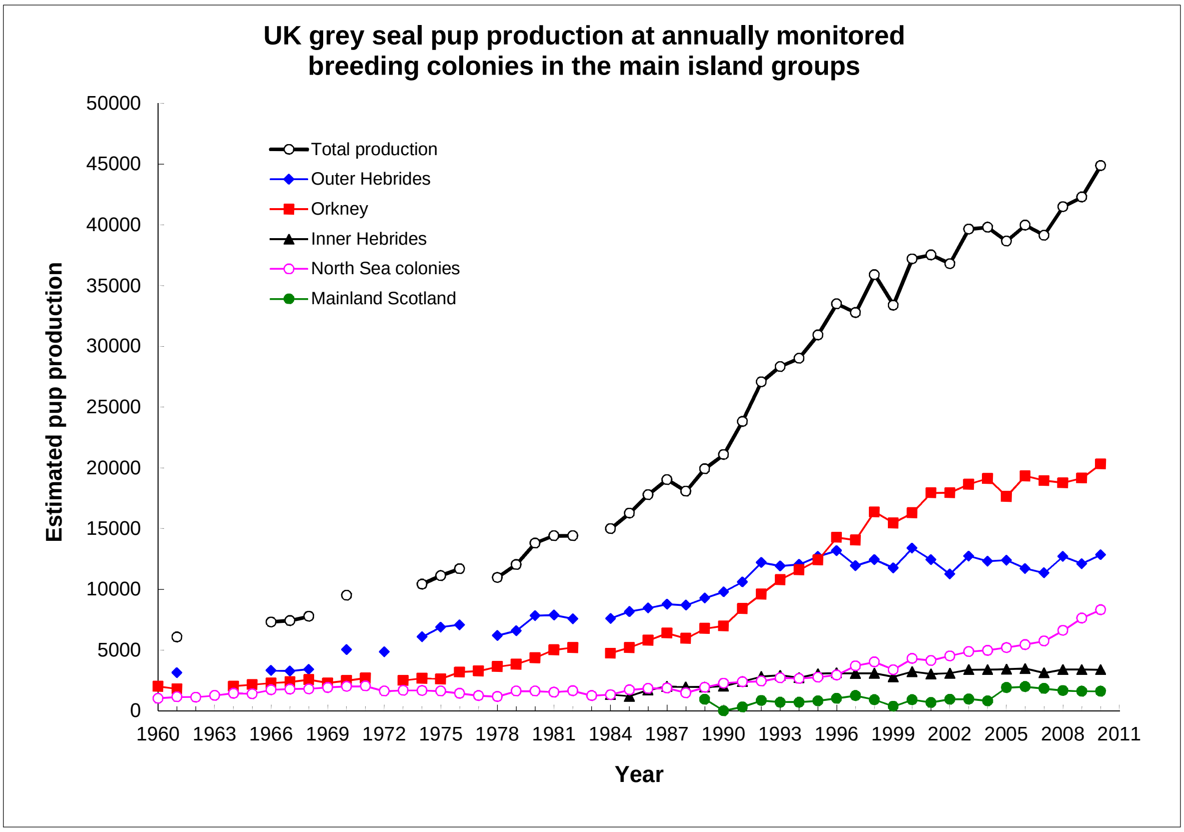
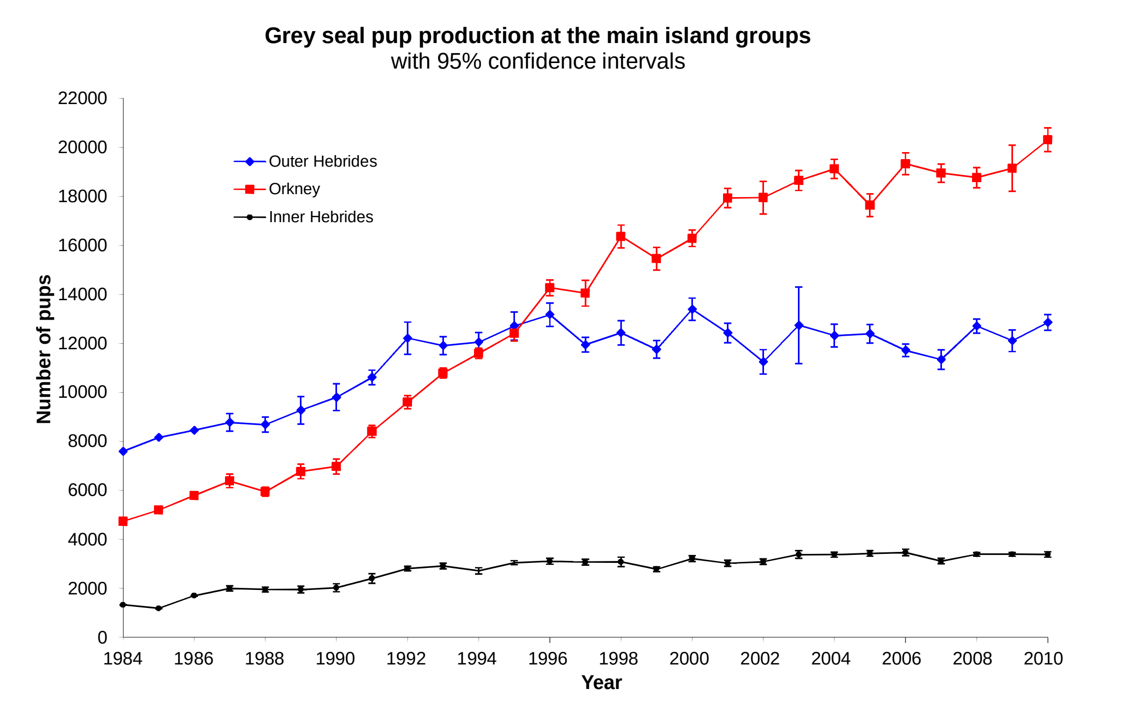
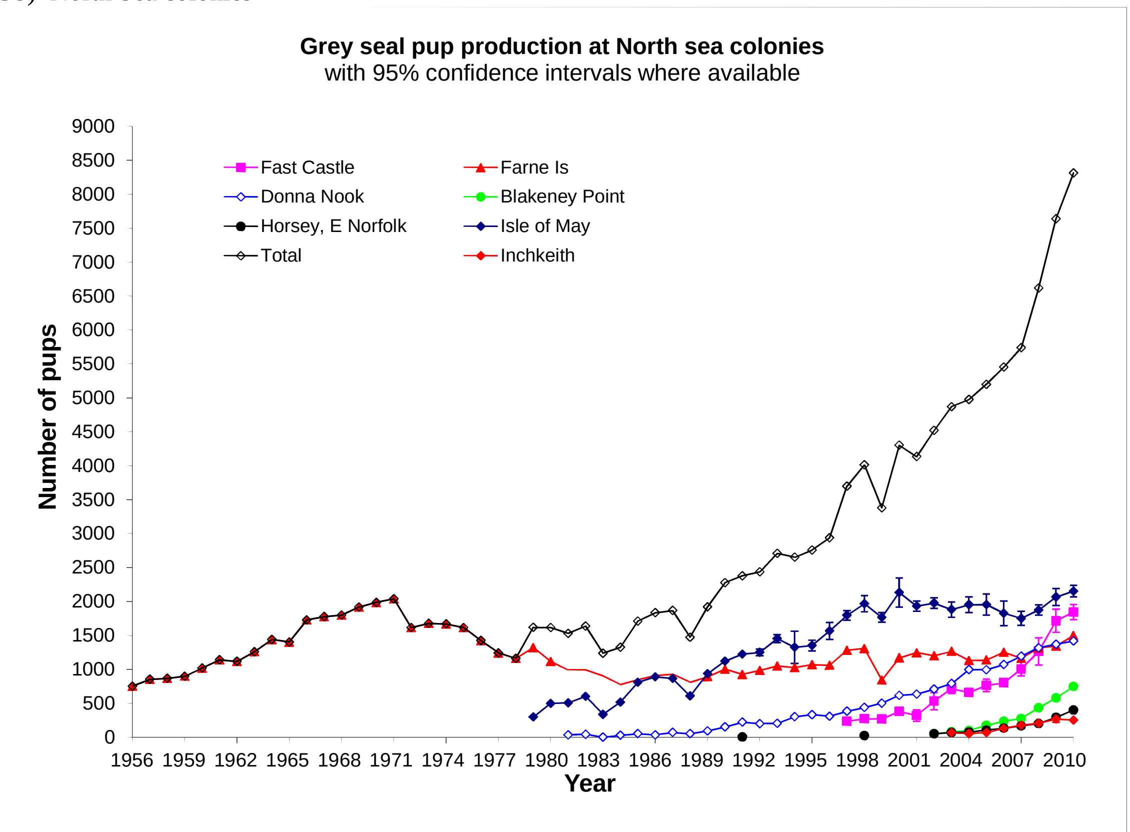


Figure 3. Trends in pup production at the major grey seal breeding colonies since 1984. Production values are shown with their 95% confidence limits where these are available. These limits assume that the various pup development parameters involved in the estimation procedure remain constant from year to year. Although they therefore underestimate total variability in the estimates, they are useful for comparing the precision of the estimates in different years. Note the difference in scale between Figures 3a and 3b.

3a) Outer Hebrides, Orkney and Inner Hebrides



3b) North Sea colonies



Len Thomas

Estimating the size of the UK grey seal population between 1984 and 2010.

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Summary

We fitted a Bayesian state-space model of British grey seal population dynamics to two sources of data: (1) regional estimates of pup production from 1984 to 2010, and (2) an independent estimate assumed to be of total population size just before the 2008 breeding season. The model (denoted EDDSNM) allowed for density dependence in pup survival, with a flexible form of density dependence, but allowed no movement of recruiting females between regions. If we assumed the coefficient of variation (CV) on pup production estimates was known, and was 10.64% (a value used in previous briefing papers), the estimated adult population size in 2010 was 124,000 (95% CI 92,600-164,200) using just the pup production estimates, and 99,300 (95% CI 80,200-122,900) using both pop production and independent total population estimates. A second model was run where the pup production CV was estimated based on realistic priors. This gave an estimated CV of 9.8% and population size estimates that were very similar to those given above.

Introduction

This paper presents updated estimates of population size and related demographic parameters, based on the models and fitting methods of Thomas (2010)[14]. Models are specified using a Bayesian state space framework, and fitted using a Monte Carlo particle filter. Only the best model from previous years' briefing papers is used (denoted EDDSNM in those papers): it assumes that density dependence occurs in pup survival, via an extended form of the Beverton-Holt function, that adult survival and fecundity are constant, and that recruiting females do not move between regions.

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 model used is a Bayesian state-space model, 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 of Thomas (2010). We followed Thomas (2010) in basing our main inferences on a model that assumed the pup production estimates are normally distributed about the actual pup production, with a fixed coefficient of variation (CV) of 10.64%. However, this value can be estimated rather than being fixed in the model – the reason for basing inference on a model with a fixed CV in previous briefing papers was to facilitate comparison among multiple population models. Here we only use one population model, so we also tried a second state-space model where the CV was estimated, with the prior distribution on this parameter being that used in past briefing papers (Table 1 of Thomas 2010).

We used the independent estimate of total population size in 2008 given by Lonergan *et al.* (2010; updated after the 2010 SCOS meeting) of 88,300 with 95% CI 75,400-105,700, which we approximated with a shifted gamma distribution as described by Thomas (2010).

As with previous briefing papers, estimates of adult female numbers from the state-space model were converted to estimates of total female numbers by multiplying by 1.73.

Model fitting used a particle filtering algorithm identical to that of Thomas (2010). In essence

[14] Note that an update was made to the briefing paper presented at the 2010 SCOS meeting, based on an updated independent estimate of total population size in 2008 (Lonergan 2010). This revised version is dated 18th March 2011, and is a supplement to the briefing papers presented to this year's SCOS.

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.

Results

Monte Carlo accuracy

The effective sample size (ESS) of 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 767.2 (Table 1), although this was reduced substantially (to 108.4) 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 3 significant figures. The ESS for the models where CV is estimated are about half the size – nor surprising given that time limitations meant that only half the number of particles were simulated. Results from this model might be considered more tenuous, except that as we shall see they are very similar to those from the fixed CV model.

Table 1. 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 fixed (i.e., known); the second model estimated this quantity.*

CV	*K* ($x10^7$)	*K** ($x10^7$)	*U* ($x10^4$)	ESS_{u1}	ESS_{u2}
Fixed	1000	41.5	49.0	767.2	108.4
Estimated	500	21.0	23.1	224.8	41.4

Model fit – CV assumed fixed

Here, we show results for the fixed CV model; those for the estimated CV model were very similar. The estimated posterior pup population trajectory (Figure 1) and demographic parameters (Figure 2) are largely very similar to those from last year's briefing paper (Thomas 2010), as one would expect when just one more year of data is added to a 26-year dataset. The model broadly provides a reasonable fit to the pup production data, but there are some clear deficiencies: it does not adequately capture the rapid rise and sudden levelling off in pup production in the Hebrides during the early 1990s, nor levelling off in Orkney in the late 1990s; it over-estimates pup production in the North Sea in the late 1990s and early 2000s, and does not track the strong increases in pup production there in the past 3 years. Addition of the 2008 independent estimate does not change the fit to pup production data greatly, although there are some changes to the model parameter estimates (Figure 2).

Table 2. Estimated size, in thousands, of the British grey seal population at the start of the 2010 breeding season, derived from the EDDSNM model 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.

CV assumed fixed		
	Pup production data only	Pup production and total population estimate
North Sea	24.6 (16.6 32.5)	19.1 (14.0 26.5)
Inner Hebrides	8.9 (7.1 10.9)	7.5 (6.2 9.0)
Outer Hebrides	33.0 (26.3 39.5)	27.6 (23.4 32.8)
Orkney	57.5 (42.6 81.3)	45.1 (36.5 54.7)
Total	124.0 (92.6 164.2)	99.3 (80.2 122.9)
CV estimated		
	Pup production data only	Pup production and total population estimate
North Sea	25.2 (17.1 33.0)	19.4 (14.1 28.3)
Inner Hebrides	8.8 (7.1 10.7)	7.5 (6.5 9.0)
Outer Hebrides	32.8 (26.3 39.8)	27.5 (22.9 32.9)
Orkney	57.9 (42.6 82.8)	45.2 (37.4 55.5)
Total	124.7 (93.1 166.3)	99.6 (80.9 125.7)

Estimates of total population size with and without the total population estimate – CV assumed fixed

The estimated trajectories of adult population size both with and without the 2008 independent estimate are shown in Figure 3 and the Appendix, and estimated adult population sizes in 2010 are given in Table 2. Note that the independent estimate of total population size for 2008 (of 88,300 with 95% CI 75,400-105,700) is substantially lower than the estimate for that year based on pup production data alone (122,100 with 95%CI 92,900-157,700), and so combining the two sources of data results in a population estimate that is a compromise between the two values (for 2008 it is 98,500 with 95%CI 80,600-119,600).

Results with CV estimated

The posterior mean CV was 9.8% both for the pup production data alone and with the addition of the independent estimate. This was slightly higher than the prior (prior mean 8.4%), and similar to the assumed value used in the fixed CV model (of 10.64%). It is therefore not surprising that the estimates for the other parameters (not shown), and for the population sizes (Table 2 and Appendix) were almost identical.

Discussion

Addition of the 2008 independent estimate reduced the estimated adult population size based on pup production data by around 20% (e.g., the 2010 estimates drop from 124,000 to 99,300). One factor that determines how much the 2008 independent population size estimate influences the results is the relative precision of the independent estimate compared with the precision of the pup production estimates. Variance of the independent estimate (CV 8.49%) comes from Lonergan (2010), and can be regarded as the best estimate available. On the other hand, the variance of the pup production estimates in the fixed CV run (CV 10.64%) comes from an estimate made by Thomas and Harwood (2009), obtained by fitting a simpler density dependent survival model to the pup count data from 1984-2008, with the observation error parameter assumed unknown rather than fixed. Pup production estimate variance is traditionally assumed fixed in SCOS analyses because this facilitates comparison between different population dynamics models (there has previously be an interest in models with density dependent fecundity); however in the current case it could be estimated if no other population models will be considered. Surprisingly, when this was done, the estimated CV was very similar to that obtained previously from the fit to a simpler model – we were anticipating that a more complex model would produce a smaller estimated CV, since the fit to the data is better. Because the estimated CV is similar to the assumed fixed CV, the two models produce very similar estimates of population size. Hence at present, we conclude that the estimates are not sensitive to (reasonable) assumptions about the CV of the pup production estimates.

We here assumed the multiplier that converts adult female population size to total population size is 1.73, equivalent to an adult sex ratio of 57% female, and is known with certainty. One potential use of the 2008 independent population size estimate, instead of using it to produce a compromise population trajectory, is to use it to estimate the adult sex ratio. This was done by Thomas (2010), who assumed a uniform prior $U(0.5,1.0)$ on sex ratio, and obtained a posterior mean ratio of 79% female (95%CI 0.59-0.98). Such analyses could be repeated this year, but would likely give similar results. This points to either some deficiency in our assumptions about sex ratio, or an inadequacy of the independent population size estimate. The conclusion of Thomas (2010) was that if uncertainty in the sex ratio was to be accounted for, it would be important to think carefully about what prior is appropriate on this parameter. We would welcome some guidance on this matter.

Other models for population dynamics are possible, and in previous years we have also run models that allow for density dependent fecundity, and models that allow movement of recruiting females between regions. Thomas and Harwood (2009) showed that there was little support from the data for the movement models, and Thomas (2010) showed the same for the fecundity model, particularly when the additional population size estimate was included. Longeran et al. (2011) have found evidence for variation in adult survival between regions, and that bears further investigation within this framework. We also anticipate that allowing annual variability in fecundity within regions (via a random effect on the fecundity parameter) would significantly improve model fit – although this may make little difference to estimated adult population size.

New estimates of other population parameters are becoming available – for example of fecundity at two intensively-monitored colonies (Smout et al. 2010). These could potentially be incorporated by revising the priors, or as observation data – the latter being more appropriate for parameters that vary through time such as through density dependence.

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Figure 1. Posterior mean estimates of true pup production from the EDDSM model 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 is10.64% . Lines show the posterior mean bracketed by the 95% credibility intervals for analyses fitted to the pup production data alone (blue lines) and to both pup production data and the 2008 total population estimate (red lines).

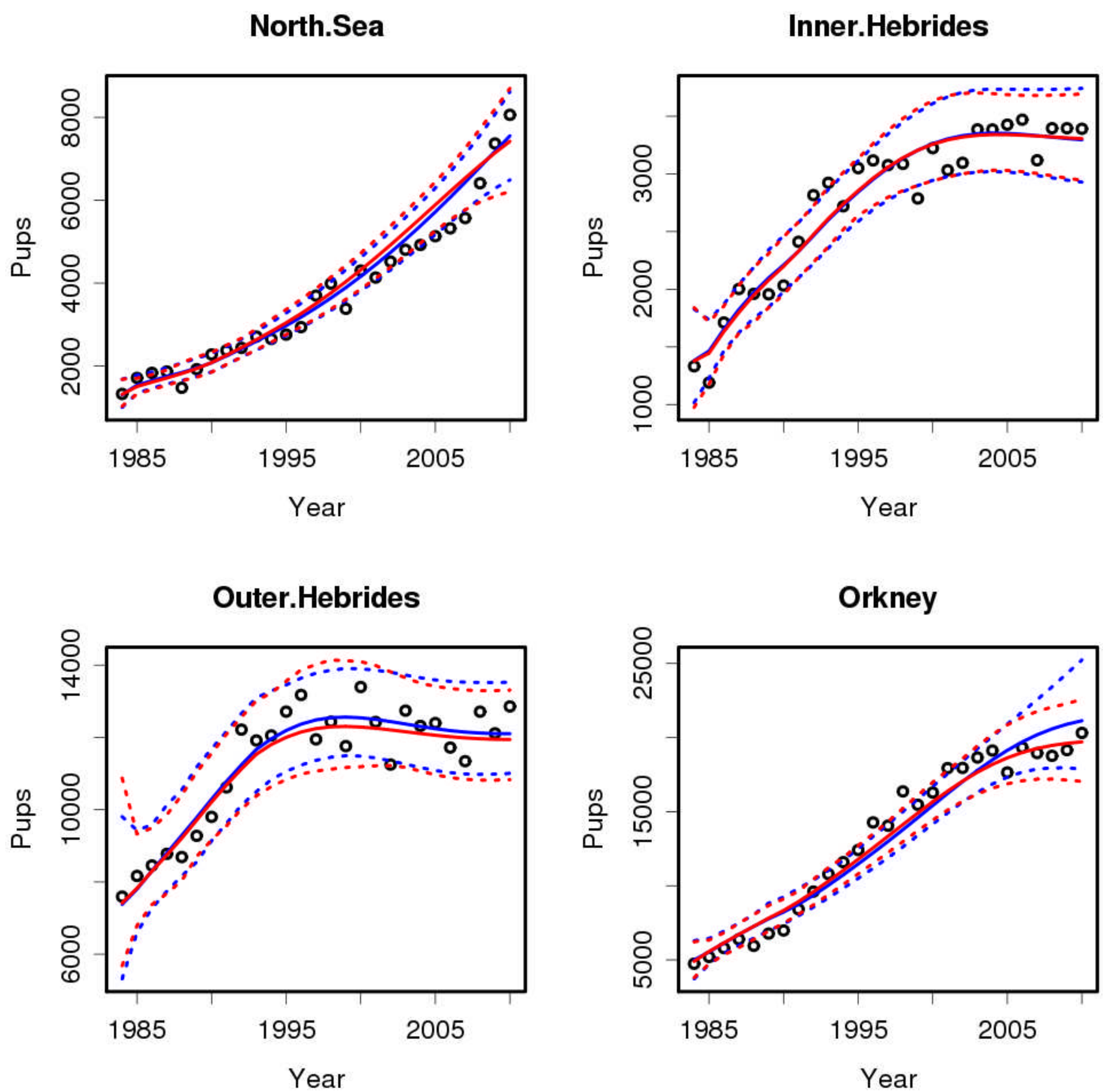
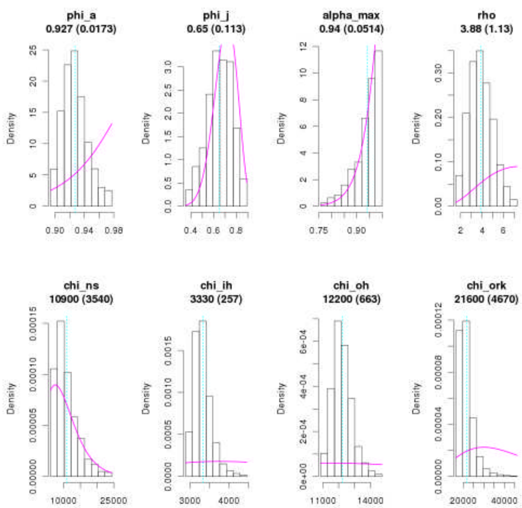


Figure 2. Posterior parameter estimates (histograms) and priors (solid lines) from the EDSSNM model of grey seal population dynamics, fit to pup production estimates from 1984-2010 (circles) and a total population estimate from 2008, assuming the CV of the pup production estimates is10.64%. The vertical line shows the posterior mean, its value is given in the title of each plot after the parameter name, with the associated standard error in parentheses.

(a) Pup production data only



(b) Pup production data and 2008 population estimate

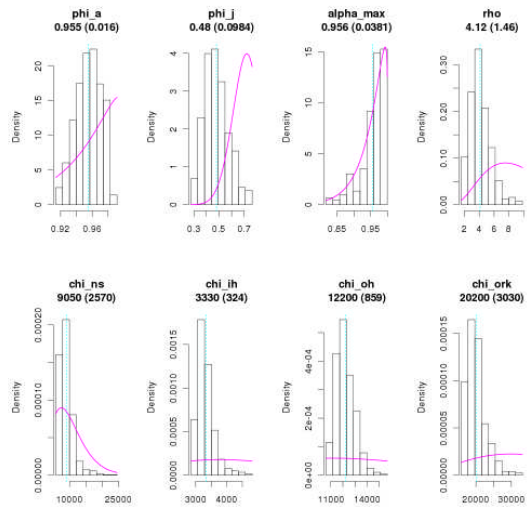
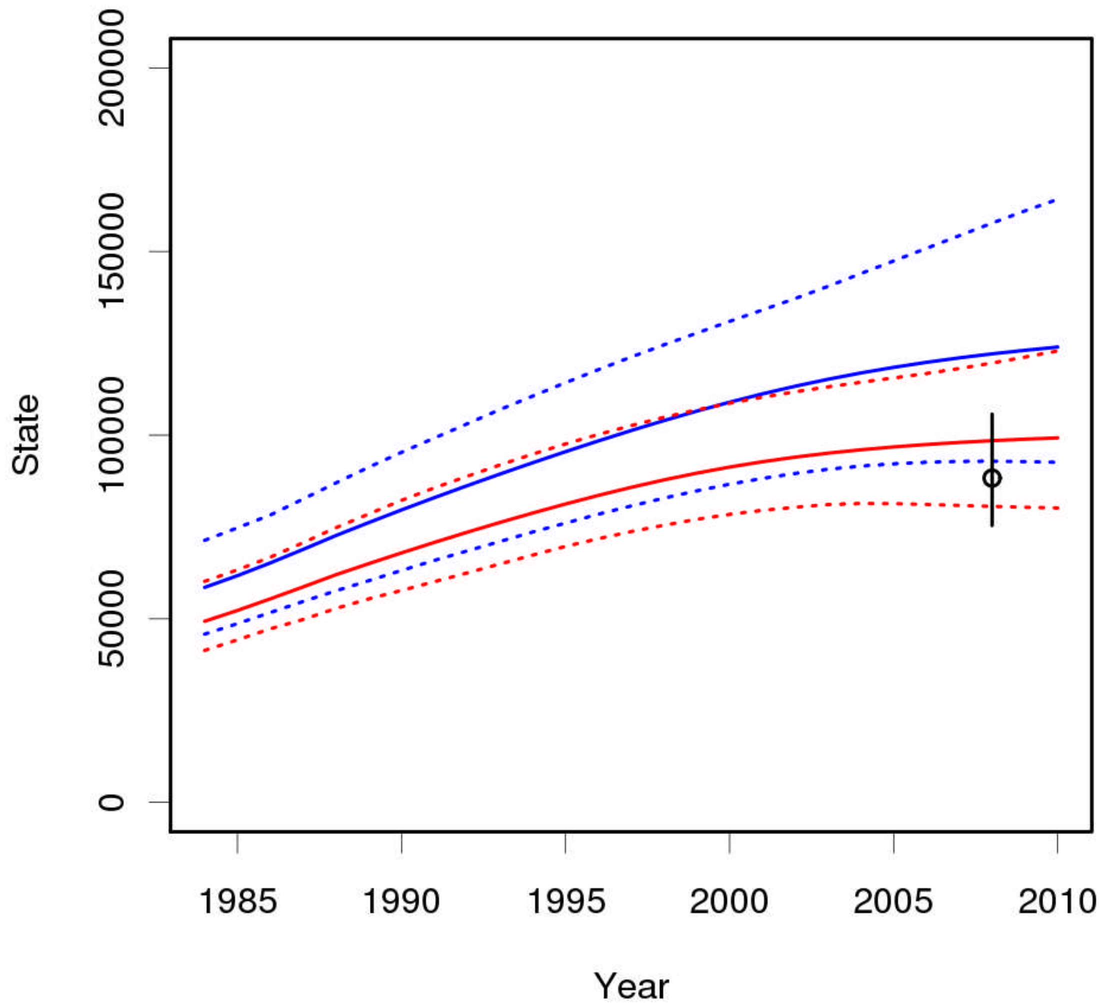


Figure 3. Posterior mean estimates of total population size from the EDDSNM model of grey seal population dynamics, fit to pup production estimates from 1984-2010 only (blue lines), and pup production estimates plus a total population estimate from 2008 (red lines), assuming the CV of the pup production estimates is10.64%. Lines show the posterior mean bracketed by the 95% credibility intervals The independent estimate is shown by a circle, with horizontal lines indicating 95% confidence interval on the estimate.



Appendix

Estimates of total population size, in thousands, at the beginning of each breeding season from 1984-2010, 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.

Table A1: Pup production data only

Year	North Sea	Inner Hebrides	Outer Hebrides	Orkney	Total
1984	5.3 (4 6.5)	5.7 (4.4 6.9)	26.5 (20.9 32.2)	21.1 (16.4 25.7)	58.5 (45.8 71.4)
1985	5.6 (4.3 6.9)	6 (4.7 7.2)	27.9 (22.1 33.8)	22.3 (17.5 26.9)	61.7 (48.7 74.8)
1986	6.1 (4.8 7.4)	6.3 (5 7.5)	29.2 (23.2 35.1)	23.7 (18.7 28.2)	65.2 (51.7 78.2)
1987	6.5 (5.1 7.9)	6.6 (5.3 7.9)	30.4 (24.3 36.7)	25.3 (20 30.2)	68.9 (54.7 82.6)
1988	7 (5.6 8.4)	7 (5.6 8.3)	31.6 (25 38.1)	27.1 (21.5 32.2)	72.7 (57.6 87)
1989	7.5 (6 9)	7.3 (5.8 8.8)	32.3 (25.5 39.1)	29 (23.1 34.5)	76.2 (60.4 91.3)
1990	8 (6.4 9.6)	7.7 (6.1 9.1)	33 (25.9 40)	31 (24.8 36.7)	79.6 (63.2 95.3)
1991	8.6 (6.9 10.2)	8 (6.3 9.5)	33.5 (26.2 40.5)	33 (26.5 39)	83 (65.9 99.2)
1992	9.2 (7.4 10.9)	8.2 (6.5 9.9)	33.8 (26.4 40.8)	35 (28.2 41.4)	86.2 (68.5 103.1)
1993	9.8 (8 11.6)	8.5 (6.7 10.2)	34 (26.5 41.1)	37.2 (29.9 44)	89.4 (71 107)
1994	10.5 (8.5 12.4)	8.7 (6.8 10.5)	34 (26.6 41.1)	39.3 (31.7 46.6)	92.5 (73.6 110.6)
1995	11.2 (9.1 13.2)	8.8 (6.9 10.8)	33.9 (26.6 41)	41.5 (33.4 49.3)	95.5 (76.1 114.3)
1996	12 (9.7 14.1)	9 (7 10.9)	33.8 (26.7 40.8)	43.7 (35.1 52)	98.4 (78.5 117.8)
1997	12.8 (10.3 15)	9 (7 11)	33.6 (26.6 40.5)	45.8 (36.7 54.7)	101.3 (80.7 121.3)
1998	13.6 (11 16)	9.1 (7.1 11.1)	33.4 (26.6 40.2)	47.9 (38.2 57.3)	104 (82.9 124.6)
1999	14.5 (11.7 17)	9.1 (7.1 11.1)	33.2 (26.5 39.9)	49.8 (39.5 59.8)	106.5 (84.8 127.8)
2000	15.3 (12.4 18.1)	9.1 (7.2 11.1)	33.1 (26.4 39.6)	51.5 (40.7 62.2)	109 (86.6 131)
2001	16.3 (13.1 19.2)	9.1 (7.2 11)	32.9 (26.4 39.4)	53 (41.6 64.4)	111.2 (88.2 134.1)
2002	17.2 (13.7 20.4)	9 (7.2 11)	32.8 (26.4 39.3)	54.3 (42.3 66.5)	113.3 (89.6 137.2)
2003	18.2 (14.4 21.7)	9 (7.2 11)	32.7 (26.3 39.2)	55.3 (42.8 68.7)	115.2 (90.7 140.5)
2004	19.2 (14.9 23)	9 (7.2 11)	32.7 (26.3 39.2)	56.1 (43.2 70.9)	116.9 (91.6 144)
2005	20.1 (15.4 24.4)	8.9 (7.1 10.9)	32.7 (26.3 39.2)	56.7 (43.4 73)	118.5 (92.2 147.4)
2006	21.1 (15.8 25.8)	8.9 (7.1 10.9)	32.7 (26.3 39.2)	57.1 (43.4 75)	119.8 (92.6 150.9)
2007	22 (16.1 27.4)	8.9 (7.1 10.9)	32.8 (26.3 39.2)	57.4 (43.4 76.8)	121 (92.8 154.3)
2008	22.9 (16.3 29)	8.9 (7.1 10.9)	32.8 (26.3 39.3)	57.5 (43.2 78.5)	122.1 (92.9 157.7)
2009	23.8 (16.5 30.7)	8.9 (7.1 10.9)	32.9 (26.3 39.4)	57.5 (42.9 80)	123.1 (92.8 161.1)
2010	24.6 (16.6 32.5)	8.9 (7.1 10.9	33 (26.3 39.5)	57.5 (42.6 81.3)	124 (92.6 164.2)

Table A2: Pup production data and 2008 total population estimate

Year	North Sea	Inner Hebrides	Outer Hebrides	Orkney	Total
1984	4.4 (3.7 5.4)	4.7 (4 5.8)	22.6 (18.7 27.5)	17.6 (15 21.5)	49.3 (41.4 60.2)
1985	4.7 (4.1 5.7)	5 (4.2 6.1)	23.8 (19.9 28.7)	18.8 (16 22.7)	52.3 (44.3 63.3)
1986	5.1 (4.4 6.2)	5.3 (4.5 6.4)	24.9 (20.9 30.1)	20.1 (17.4 24.1)	55.4 (47.3 66.8)
1987	5.5 (4.8 6.6)	5.6 (4.8 6.8)	25.9 (21.5 31.5)	21.6 (18.7 25.9)	58.7 (49.8 70.7)
1988	6 (5.1 7.1)	5.9 (5.1 7.2)	26.9 (22.4 32.8)	23.2 (20.2 27.7)	62 (52.8 74.8)
1989	6.4 (5.5 7.7)	6.2 (5.3 7.6)	27.5 (23 33.6)	24.8 (21.6 29.7)	65 (55.4 78.5)
1990	6.9 (5.9 8.2)	6.5 (5.5 7.9)	28 (23.3 34.4)	26.6 (23 31.7)	67.9 (57.7 82.2)
1991	7.4 (6.3 8.8)	6.8 (5.6 8.3)	28.3 (23.6 34.7)	28.3 (24.6 33.9)	70.8 (60.1 85.6)
1992	7.9 (6.7 9.4)	7 (5.8 8.5)	28.5 (23.7 35)	30.1 (26.2 35.9)	73.6 (62.5 88.8)
1993	8.5 (7.2 10.1)	7.2 (6 8.8)	28.6 (23.9 35)	31.9 (27.8 38)	76.2 (64.9 91.9)
1994	9.1 (7.7 10.8)	7.3 (6.1 9)	28.6 (24.1 34.9)	33.8 (29.5 40.1)	78.8 (67.3 94.8)
1995	9.7 (8.3 11.5)	7.4 (6.2 9.2)	28.5 (24.2 34.7)	35.5 (31 42.2)	81.3 (69.7 97.6)
1996	10.4 (8.9 12.3)	7.5 (6.2 9.3)	28.4 (24.2 34.4)	37.3 (32.5 44.2)	83.6 (71.8 100.2)
1997	11.1 (9.5 13.1)	7.6 (6.3 9.3)	28.3 (24.2 34)	38.9 (33.8 46.2)	85.8 (73.7 102.6)
1998	11.8 (10.1 13.9)	7.6 (6.3 9.3)	28.1 (24.1 33.6)	40.3 (34.9 48)	87.8 (75.5 104.9)
1999	12.5 (10.7 14.8)	7.6 (6.4 9.3)	28 (24.1 33.3)	41.6 (35.9 49.6)	89.7 (77.1 106.9)
2000	13.2 (11.3 15.6)	7.6 (6.4 9.2)	27.9 (23.9 33)	42.6 (36.8 50.9)	91.3 (78.4 108.7)
2001	13.9 (11.8 16.5)	7.6 (6.4 9.2)	27.7 (23.8 32.8)	43.5 (37.5 51.9)	92.8 (79.5 110.3)
2002	14.7 (12.2 17.5)	7.6 (6.4 9.1)	27.7 (23.7 32.6)	44.1 (38 52.6)	94 (80.4 111.8)
2003	15.4 (12.6 18.5)	7.5 (6.4 9.1)	27.6 (23.7 32.5)	44.6 (38.4 53.2)	95.1 (81.1 113.1)
2004	16 (13 19.5)	7.5 (6.4 9)	27.5 (23.6 32.4)	44.9 (38.4 53.5)	96 (81.4 114.4)
2005	16.7 (13.3 20.5)	7.5 (6.3 9)	27.5 (23.5 32.4)	45.1 (38.2 53.7)	96.8 (81.4 115.6)
2006	17.3 (13.5 21.6)	7.5 (6.3 9)	27.5 (23.5 32.4)	45.2 (37.9 53.8)	97.5 (81.1 116.8)
2007	17.8 (13.7 22.7)	7.5 (6.3 9)	27.5 (23.5 32.5)	45.2 (37.5 54)	98 (80.9 118.1)
2008	18.3 (13.8 23.9)	7.5 (6.2 9)	27.6 (23.4 32.6)	45.2 (37.1 54.2)	98.5 (80.6 119.6)
2009	18.7 (13.9 25.2)	7.5 (6.2 9)	27.6 (23.4 32.7)	45.1 (36.8 54.4)	98.9 (80.4 121.3)
2010	19.1 (14 26.5)	7.5 (6.2 9)	27.6 (23.4 32.8)	45.1 (36.5 54.7)	99.3 (80.2 122.9)

Table A3: Pup production data only, estimated CV

Year	North Sea	Inner Hebrides	Outer Hebrides	Orkney	Total
1984	5.3 (4.1 6.4)	5.7 (4.5 7)	26.3 (20.8 32.4)	21 (16.4 27)	58.2 (45.8 72.8)
1985	5.6 (4.4 6.9)	5.9 (4.8 7.2)	27.7 (22 33.8)	22.2 (17.6 28.4)	61.4 (48.8 76.3)
1986	6 (4.8 7.4)	6.3 (5.1 7.4)	29 (23.2 35)	23.6 (18.9 29.5)	64.9 (52.1 79.3)
1987	6.5 (5.3 7.9)	6.6 (5.3 7.9)	30.3 (24.3 36.5)	25.2 (20.4 31.4)	68.6 (55.3 83.7)
1988	7 (5.7 8.4)	7 (5.6 8.4)	31.4 (25 38)	27 (21.9 33.6)	72.4 (58.3 88.4)
1989	7.5 (6.2 9)	7.3 (5.9 8.6)	32.2 (25.4 38.7)	28.9 (23.5 35.9)	75.9 (60.9 92.3)
1990	8 (6.6 9.6)	7.7 (6.1 9)	32.9 (25.7 39.5)	30.8 (25.1 38.4)	79.4 (63.5 96.5)
1991	8.6 (7.1 10.2)	8 (6.3 9.4)	33.3 (26 40.2)	32.9 (26.7 41)	82.7 (66.1 100.8)
1992	9.2 (7.6 10.9)	8.2 (6.5 9.7)	33.7 (26.3 40.7)	34.9 (28.5 43.3)	86 (68.8 104.5)
1993	9.8 (8.1 11.6)	8.5 (6.7 10.1)	33.8 (26.5 41.1)	37.1 (30.4 45.9)	89.2 (71.6 108.6)
1994	10.5 (8.7 12.3)	8.6 (6.8 10.4)	33.9 (26.6 41.4)	39.3 (32.2 48.5)	92.3 (74.4 112.6)
1995	11.2 (9.3 13.2)	8.8 (6.9 10.6)	33.8 (26.8 41.5)	41.5 (34 50.9)	95.3 (77 116.1)
1996	12 (9.9 14)	8.9 (7 10.8)	33.7 (26.8 41.2)	43.7 (35.7 53.4)	98.3 (79.4 119.5)
1997	12.8 (10.6 15)	9 (7 10.9)	33.5 (26.7 41.1)	45.9 (37.3 55.8)	101.1 (81.6 122.8)
1998	13.6 (11.2 15.9)	9 (7.1 11)	33.3 (26.7 40.9)	47.9 (38.6 58.1)	103.9 (83.6 125.8)
1999	14.5 (11.9 16.9)	9 (7.2 11)	33.1 (26.6 40.6)	49.8 (39.8 60.1)	106.5 (85.5 128.7)
2000	15.4 (12.6 18)	9 (7.2 10.9)	33 (26.5 40.4)	51.6 (40.8 62.1)	109 (87.1 131.4)
2001	16.3 (13.2 19.1)	9 (7.2 10.9)	32.8 (26.4 40.2)	53.1 (41.6 64)	111.3 (88.4 134.2)
2002	17.3 (13.9 20.2)	9 (7.2 10.8)	32.7 (26.3 40)	54.4 (42.2 66.4)	113.4 (89.5 137.4)
2003	18.3 (14.5 21.5)	8.9 (7.2 10.8)	32.6 (26.2 39.9)	55.5 (42.6 68.9)	115.4 (90.5 141)
2004	19.3 (15.1 22.8)	8.9 (7.2 10.8)	32.6 (26.2 39.8)	56.3 (42.9 71.5)	117.2 (91.4 144.8)
2005	20.3 (15.7 24.2)	8.9 (7.2 10.7)	32.6 (26.2 39.7)	57 (43.4 73.6)	118.8 (92.4 148.3)
2006	21.3 (16.2 25.8)	8.8 (7.1 10.7)	32.6 (26.2 39.7)	57.4 (43.6 75.7)	120.2 (93.2 151.8)
2007	22.3 (16.6 27.4)	8.8 (7.1 10.7)	32.7 (26.2 39.7)	57.7 (43.4 77.7)	121.5 (93.4 155.5)
2008	23.3 (16.8 29.2)	8.8 (7.1 10.7)	32.7 (26.2 39.7)	57.8 (43.2 79.4)	122.7 (93.4 159)
2009	24.3 (17 31.1)	8.8 (7.1 10.7)	32.8 (26.3 39.7)	57.9 (42.8 81.2)	123.8 (93.2 162.6)
2010	25.2 (17.1 33)	8.8 (7.1 10.7)	32.8 (26.3 39.8)	57.9 (42.6 82.8)	124.7 (93.1 166.3)

Table A4: Pup production data and 2008 total population estimate, estimated CV

Year	North Sea	Inner Hebrides	Outer Hebrides	Orkney	Total
1984	4.4 (3.8 5.3)	4.8 (3.9 5.8)	22.3 (18.4 27.8)	17.9 (14.8 21.4)	49.4 (40.8 60.4)
1985	4.8 (4.1 5.7)	5 (4.2 6.1)	23.4 (18.8 29.2)	19.1 (16.2 22.6)	52.4 (43.3 63.5)
1986	5.2 (4.5 6.1)	5.3 (4.5 6.4)	24.5 (19.9 30.3)	20.5 (17.4 24.1)	55.5 (46.3 66.9)
1987	5.6 (4.9 6.6)	5.7 (4.8 6.8)	25.6 (21 31.6)	22 (18.8 25.6)	58.8 (49.5 70.6)
1988	6 (5.3 7.1)	6 (5.1 7.2)	26.5 (21.3 32.8)	23.6 (20.3 27.4)	62.1 (52.1 74.6)
1989	6.5 (5.7 7.7)	6.3 (5.3 7.5)	27.1 (21.5 33.5)	25.3 (21.9 29.3)	65.2 (54.4 78)
1990	7 (6.1 8.2)	6.5 (5.5 7.9)	27.6 (21.7 34.1)	27 (23.5 31.4)	68.1 (56.8 81.6)
1991	7.5 (6.5 8.8)	6.8 (5.6 8.2)	27.9 (21.9 34.6)	28.8 (25 33.5)	71 (59 85.1)
1992	8 (7 9.5)	7 (5.7 8.5)	28.1 (22 34.8)	30.6 (26.5 35.5)	73.7 (61.2 88.3)
1993	8.6 (7.4 10.1)	7.2 (5.8 8.8)	28.2 (22.1 34.9)	32.4 (28 37.7)	76.4 (63.4 91.5)
1994	9.2 (8 10.9)	7.4 (5.9 9)	28.3 (22.2 35)	34.2 (29.4 40)	79 (65.5 94.9)
1995	9.9 (8.5 11.7)	7.5 (6 9.2)	28.2 (22.3 34.8)	35.9 (30.8 42.2)	81.5 (67.6 97.9)
1996	10.6 (9.1 12.5)	7.6 (6 9.3)	28.1 (22.4 34.5)	37.6 (31.9 44.3)	83.8 (69.4 100.6)
1997	11.3 (9.7 13.3)	7.6 (6.1 9.4)	28 (22.5 34.2)	39.1 (33 46.2)	86 (71.3 103)
1998	12 (10.3 14.1)	7.7 (6.2 9.4)	27.9 (22.5 33.9)	40.5 (34.1 48)	88 (73.1 105.3)
1999	12.7 (11 15)	7.7 (6.2 9.3)	27.8 (22.6 33.6)	41.7 (35 49.6)	89.9 (74.8 107.6)
2000	13.5 (11.6 15.9)	7.7 (6.3 9.3)	27.6 (22.6 33.4)	42.7 (35.8 51)	91.5 (76.3 109.5)
2001	14.2 (12.2 16.9)	7.7 (6.3 9.2)	27.5 (22.7 33.2)	43.5 (36.5 52)	92.9 (77.7 111.2)
2002	15 (12.7 17.8)	7.6 (6.3 9.1)	27.5 (22.7 33)	44.1 (37.1 52.6)	94.2 (78.8 112.5)
2003	15.7 (13.1 18.8)	7.6 (6.4 9.1)	27.4 (22.7 32.8)	44.6 (37.6 53.1)	95.3 (79.8 113.8)
2004	16.4 (13.4 19.9)	7.6 (6.4 9.1)	27.4 (22.8 32.7)	44.9 (38.1 53.6)	96.2 (80.6 115.2)
2005	17 (13.7 21.1)	7.6 (6.4 9)	27.4 (22.8 32.6)	45.1 (38.3 54)	97 (81.2 116.7)
2006	17.6 (13.9 22.4)	7.6 (6.4 9)	27.4 (22.8 32.6)	45.2 (38.2 54.3)	97.7 (81.3 118.4)
2007	18.1 (14 23.8)	7.5 (6.4 9)	27.4 (22.9 32.7)	45.2 (38 54.6)	98.2 (81.3 120.1)
2008	18.6 (14.1 25.3)	7.5 (6.4 9)	27.4 (22.9 32.7)	45.2 (37.8 54.9)	98.7 (81.2 121.9)
2009	19 (14.1 26.8)	7.5 (6.5 9)	27.4 (22.9 32.8)	45.2 (37.6 55.2)	99.2 (81.1 123.8)
2010	19.4 (14.1 28.3)	7.5 (6.5 9)	27.5 (22.9 32.9)	45.2 (37.4 55.5)	99.6 (80.9 125.7)

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The status of British harbour seal populations in 2010

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Summary

In August 2010, the Sea Mammal Research Unit (SMRU) resurveyed Orkney only, to investigate whether previously observed declines in number s of harbour seals in the island group continued. Harbour seals between the Humber Estuary and east Norfolk in England 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, 2010).

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 2010, the minimum number of harbour seals counted in Scotland was **20,461**and in England **4,227** making a total for Great Britain of **24,688** (Table 1). In 2002, **1,248** harbour seals were counted in Northern Ireland, making a UK total of **25,936**.

The number of harbour seals counted in Orkney in 2010was **2,688**, 6.2% lower than the last complete count of **2,867**in 2008.In the Moray Firth, both breeding season and moult counts were higher in 2010 than in 2009. In the Firth of Tay, the 2010 count (124) was 10.5% higher than the all-time low in 2009 (111), still a very low number.

During the 2010 breeding season, SMRU conducted five aerial surveys of harbour seals breeding in the Moray Firth, continuing the time series started by the University of Aberdeen. A series of 5 breeding season surveys were also carried out in England, between the Humber Estuary and Scroby Sands between 19/6 and 12/7 2010 (results are presented in SCOS BP 11/4).

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 haulout 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). Between2007 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 2010, as between 2007 and 2009, 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 haulout groups and will be used to determine the age and sex structure of grey seals. The grey seal data has been used to inform the models used to estimate the total grey seal population size(seeSCOS BP 10/4, Lonergan *et al*. in press).

In England, the Lincolnshire and Norfolk coast, which holds over 95% 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.

In August 2011, with additional funding from SNH, Northern Ireland Environment Agency and the Irish National Parks and Wildlife Service, surveys will cover the Outer Hebrides, east and north coasts of Scotland, Northern Ireland 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 haulout 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 between2007 and 2010 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 2010, 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 value has been used.

The most recent minimum estimate of the number of harbour seals in Scotland is **20,461**from surveys carried out between 2007 and 2010 (Table 1). This is 29.0% lower than the total for Scotland (28,812) from surveys carried out between 2000 and 2005 (Table 1). The most recent minimum estimate for England is **4,227**, which is 5% higher than the 2009 count of **4,000**. The 2010 count comprises 3,860 seals in Lincolnshire and Norfolk plus 347seals in Northumberland, Cleveland, Essex and Kent between 2007 and 2008 and an estimated 20 seals from the south and west coasts. Including the **1,248** harbour seals counted in Northern Ireland in 2002, gives a UK total of **25,936**

2. Harbour seals in Scotland: moult

In August 2010, only Orkney and the adjacent part of the north coast of Scotland was surveyed in addition to the annual surveys of the Moray Firth and Firth of Tay. The number and distribution of harbour seals counted in Orkney during the thermal imaging surveys in August 2010 are shown in Figure 2 with the distribution of grey seals in Figure 3. The number of harbour seals counted in Orkney in 2010 (2,688) was slightly lower (by 6.2%) than the previous complete Orkney count in 2008 (2,867).

The trends in counts of harbour seals in different areas (based on Seal Management Areas) of Scotland, from surveys carried out between 1988 and 2010 are shown in Figure 6 with numbers in Table 1.

Moray Firth

AberdeenUniversity'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 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. The 2010August countwas the highest since 1997(Table 2). Following years of decline, harbour seal numbers in the Moray firth have increased in the past two years (Figure8; 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 2010 count for the Firth of Tay (124) was 11.7% higher than the 2009 count (111). Numbers in this Special Area of Conservation (SAC) in 2010 were only 19.3% of themean of countsbetween 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 2010, six dead pregnant harbour seals were found around the Eden and Tay estuaries, with corkscrew injuries. By mid-July 2011, three more pregnant females were found. This level of mortality will seriously impinge on this population's ability to recover from the recent decline. 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 2010 breeding season, SMRU conducted five air surveys harbour seals in the Moray Firth between mid June and mid July. The mean number of adults counted during these surveys, with standard errors, is shown in Figure 7a. The mean count of harbour seals in the Inner Moray Firth, between Ardersier and Loch Fleet, in 2010(721) was 6.0% greater than the 2009 mean count (679). The 2010 mean count in the Outer Moray Firth, between Findhorn and Helmsdale (821), was4.3% greater than the 2009 mean count (787).

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 2010 (Tables 1 and 4). The second count (14/08/10) was 36% lower than the earlier count (8/08/10). There were indications that higher levels of boat activity particularly the location of the cockle fishing fleets may have influenced haulout behaviour in the later count. The undisturbed count of 3086 harbour seals in the Wash 9% higher than the 2009 counts and 53% higher than the mean of the 2008 counts which were similar to the counts over the previous 4 years.

Overall, the combined count for the English East coast population (Donna Nook to Scroby Sands) in 2010 was 2% higher than the 2009 count and 40% 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 WaddenSea population that has been increasing consistently since 2002 and increased by 12% between 2008 and 2009. .

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 50 (mean count of 53 in August 2010; Woods 2008; Woods 2009; Woods 2010). Low butincreasingnumbers of pups are born (11 born and survived to weaning in 2010).

5. Harbour seals in England: breeding season

Apeak count of 1,432 pups and 3,702 older seals (1+ age classes) was obtained in The Wash during the 2010 breeding season survey compared with 1,130pups and 2,523 older seals in July 2009. Pups were widely distributed, being present at all occupied sites in 2010. The 2010 pup and adult counts were 27% and 47% higher respectively than the 2009 counts, and 42% and 67% higher than the average pup and adult counts for 2006 to 2008. 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 14% increase in pup count in 2009 and the further 27% increase in 2010 is consistent with the recent large increases in the moult count.

6. Proposed harbour seal surveys 2011

Breeding season: Moray Firth

Five breeding season fixed-wing surveys were carried out in the Moray Firth between 16 June and 14 July 2011.The fourth survey (9 and 10 July) was not completed due to persistent rain and thunderstorms over the Moray Firth.

The Wash, Donna Nook and Blakeney Point

A single survey was carried out on 2nd July 2011 between Donna Nook and Goodwin Sands in Kent.

Moult - 2011 surveys

In Scotland, surveys of the east and north coasts and of the Outer Hebrides are planned for August 2011weather and equipment permitting. Northern Ireland and part of the Republic of Ireland are 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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Woods, R. (2010) Tees Seals Research Programme, Monitoring Report No. 22. (1989–2010). Unpublished report to the Industry Nature Conservation Association.

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 2009.**

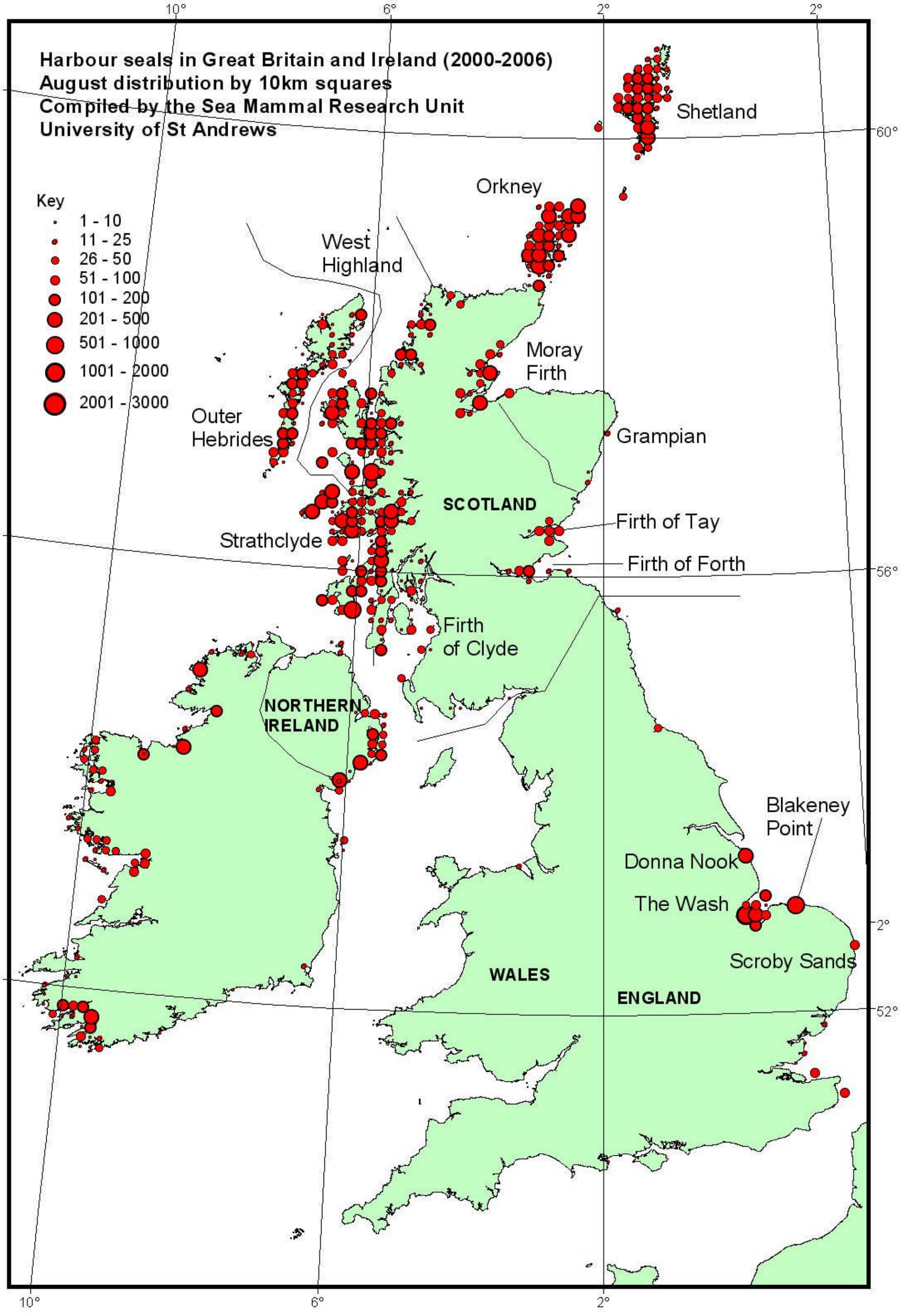


Figure 2. Harbour seals in Orkney, surveyed in August 2010.

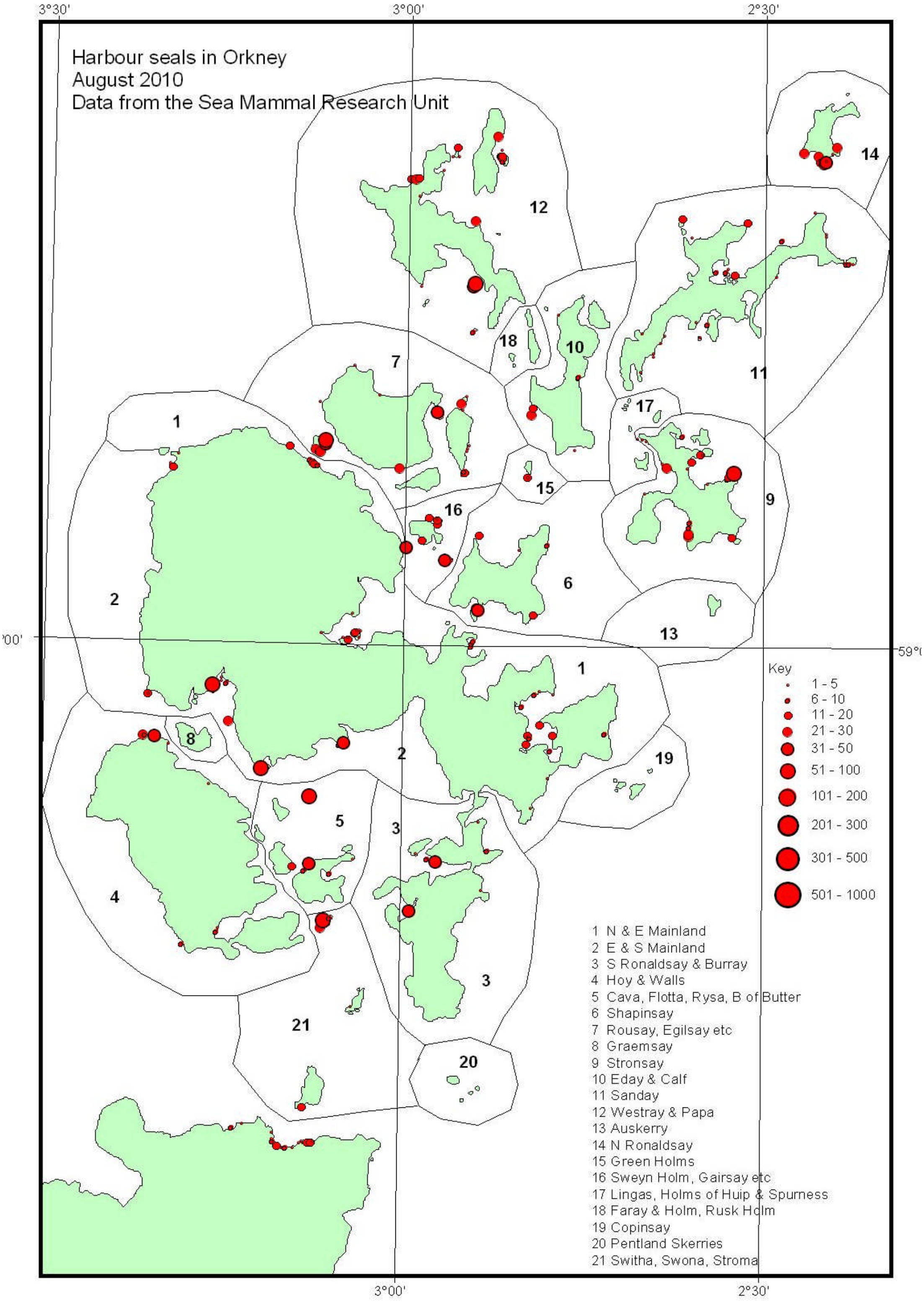


Figure 3. Grey seals in Orkney, surveyed in August 2010.

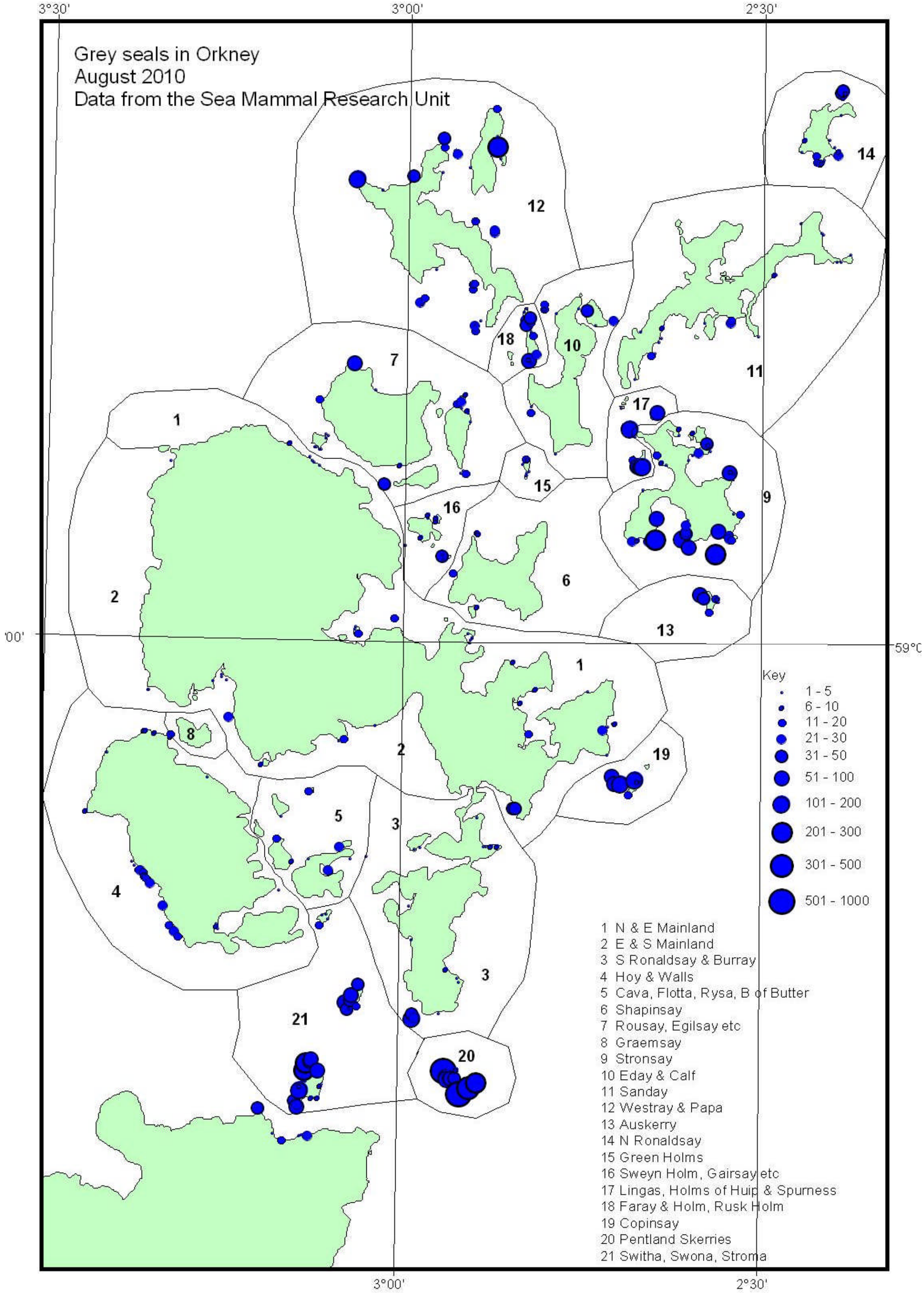


Figure 4. The number and distribution of harbour seals in Management Areas around the coast of Scotland, from surveys carried out between August 2007 and 2009. All areas were surveyed by helicopter using a thermal imaging camera.

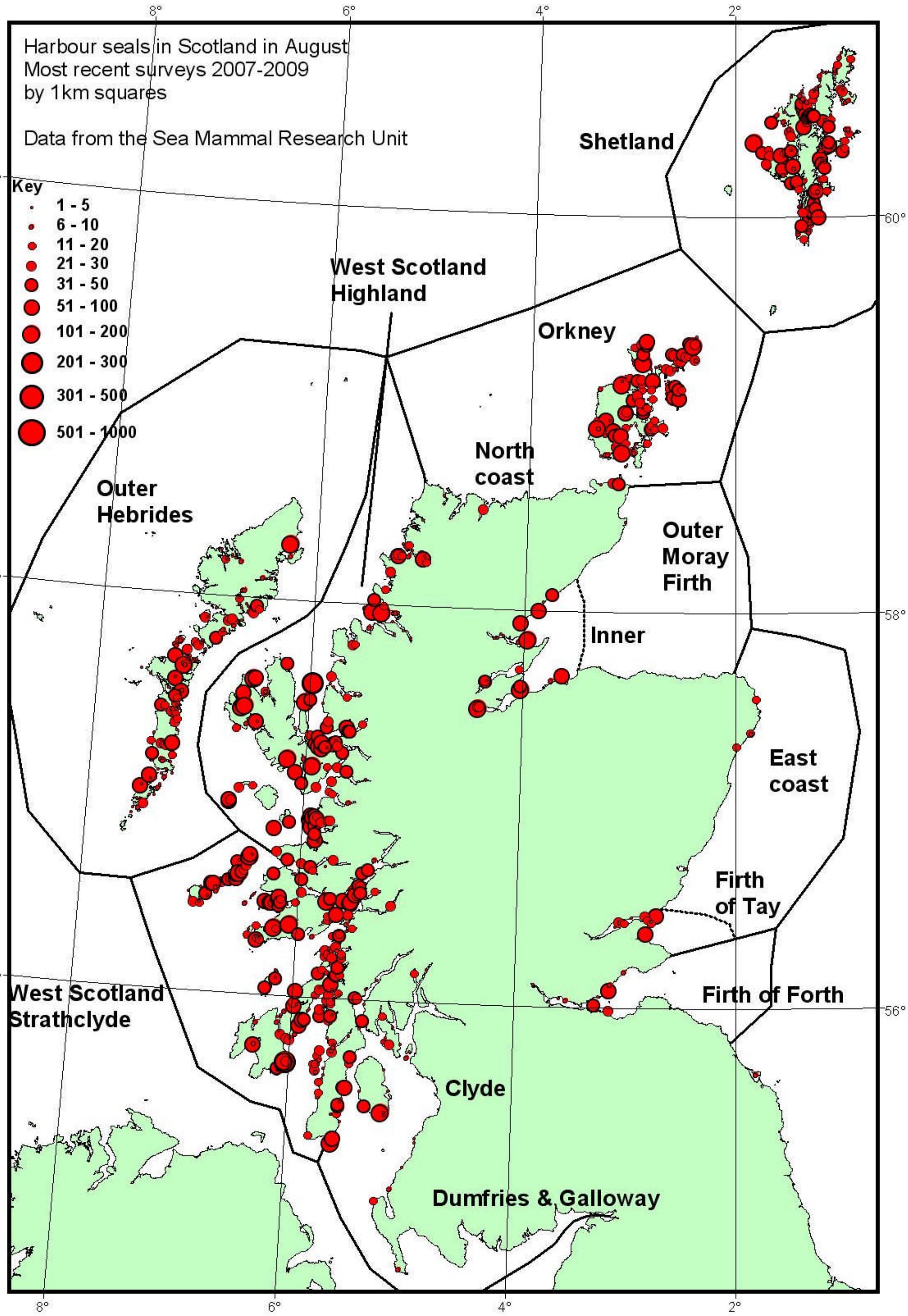


Figure 5. The number and distribution of grey seals in Management Areas around the coast of Scotland, from surveys carried out between August 2007 and 2009. All areas were surveyed by helicopter using a thermal imaging camera.

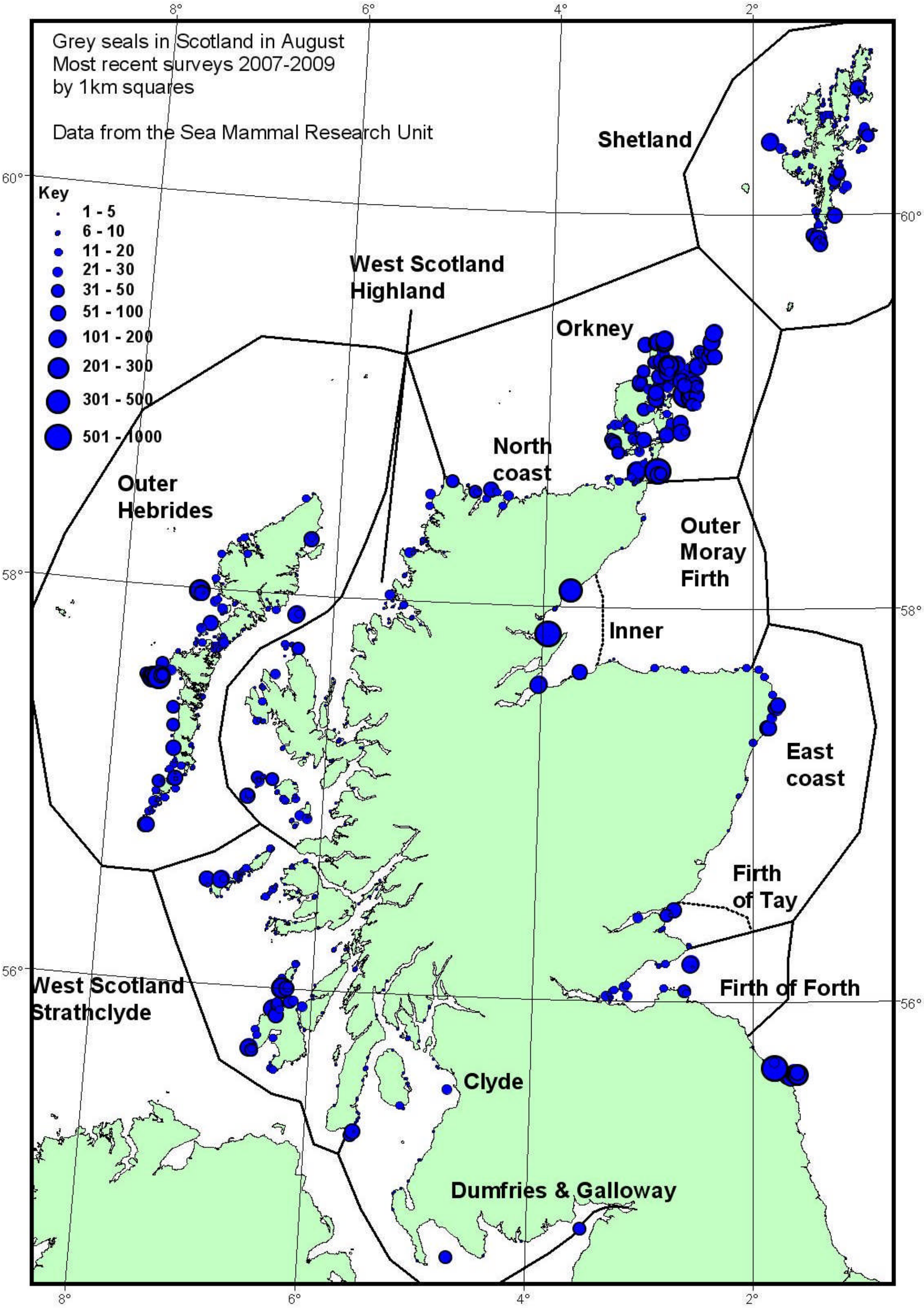


Figure 6.Trends in counts of harbour seals in Management Areas around Scotland. Data from the Sea Mammal Research Unit. Solid symbols show where data were from one or two years; open symbols show where data were collected over more than two years.

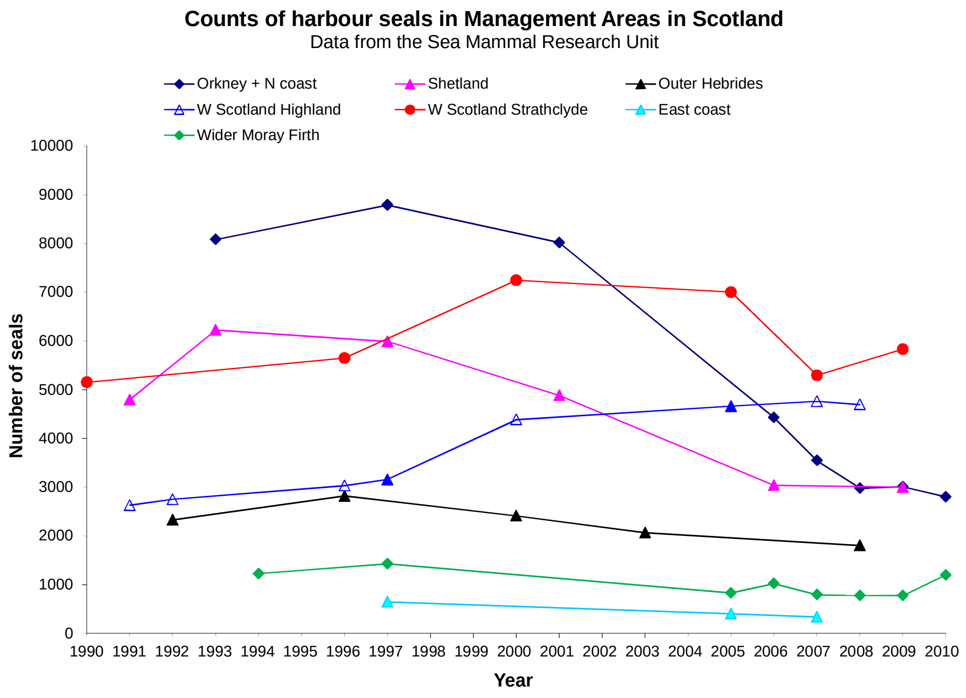
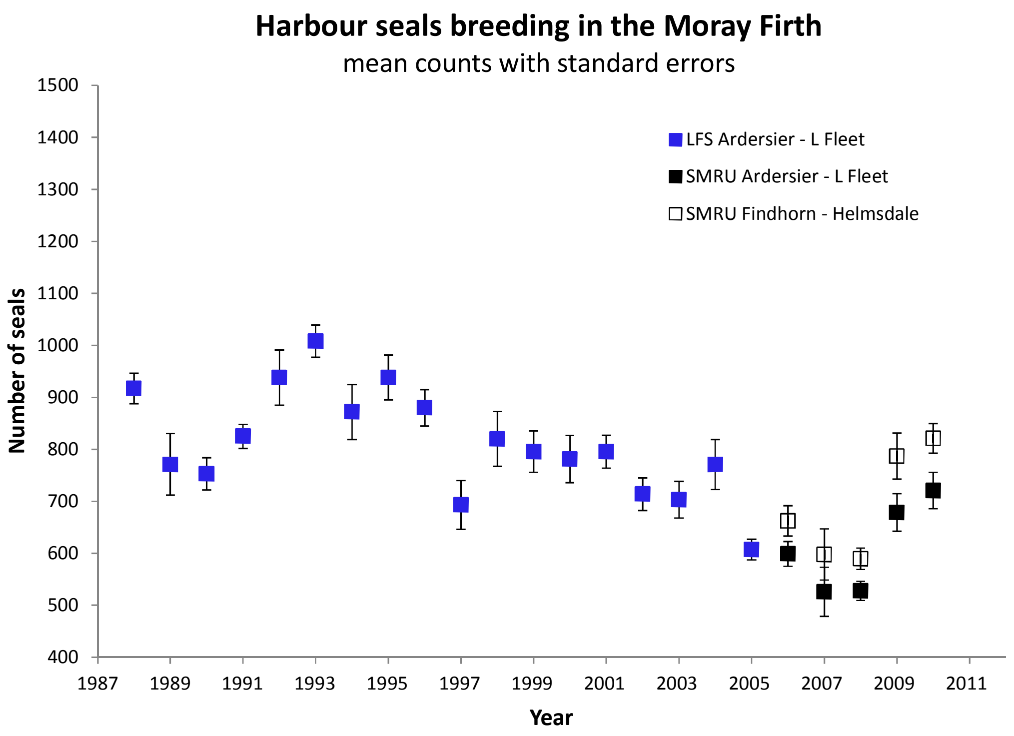


Figure 7. Trends in harbour seal numbers in the Moray Firth since 1988. Seals were counted during their breeding season (a) and during their moult (b) by the University of Aberdeen's Lighthouse Field Station (LFS) and more recently by SMRU. Comparable areas are the Inner Firths plus Loch Fleet. SMRU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

a)



b)

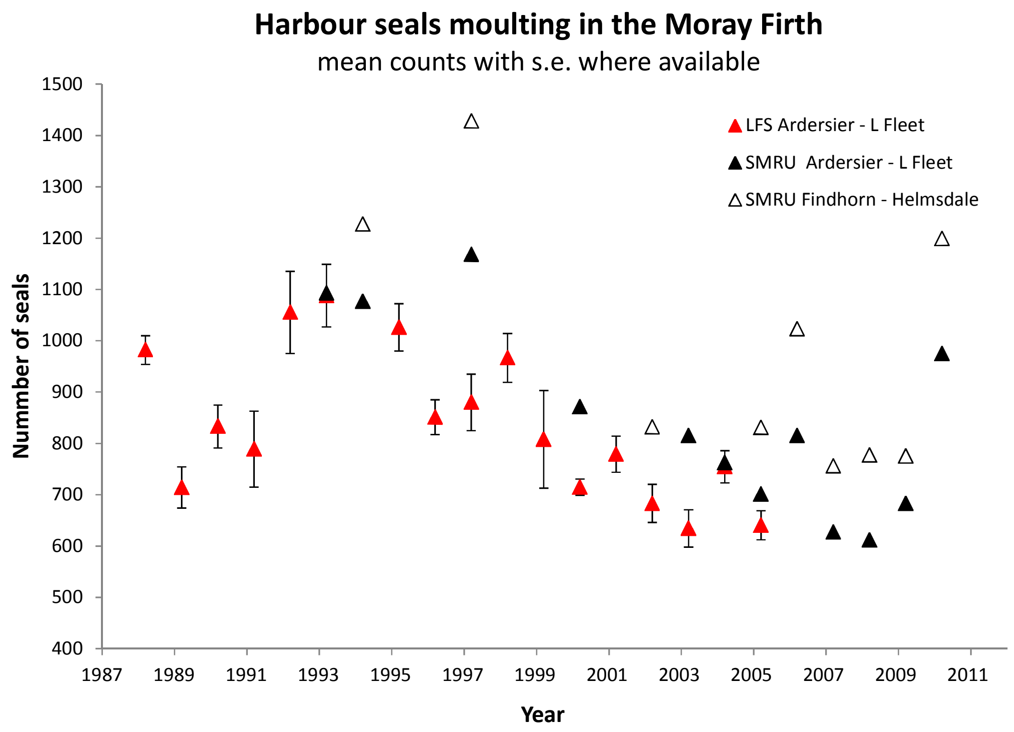


Figure 8. The number of harbour seals counted in areas within the Moray Firth between 1992 and 2010 by the Sea Mammal Research Unit.

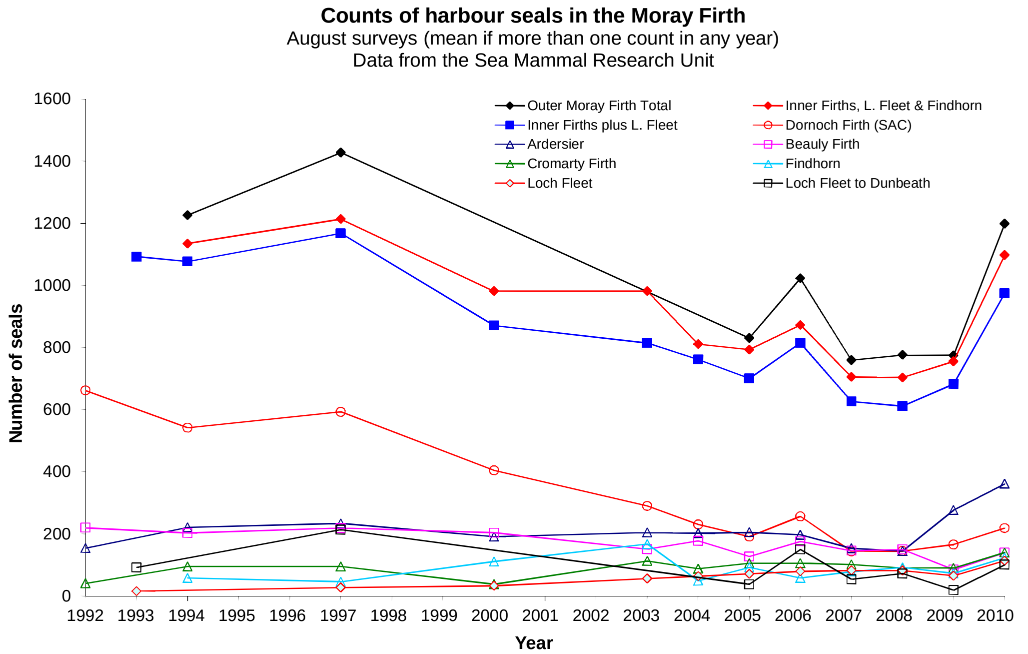


Figure 9. The number of harbour seals counted in the Firth of Tay between 1990 and 2010 by the Sea Mammal Research Unit.

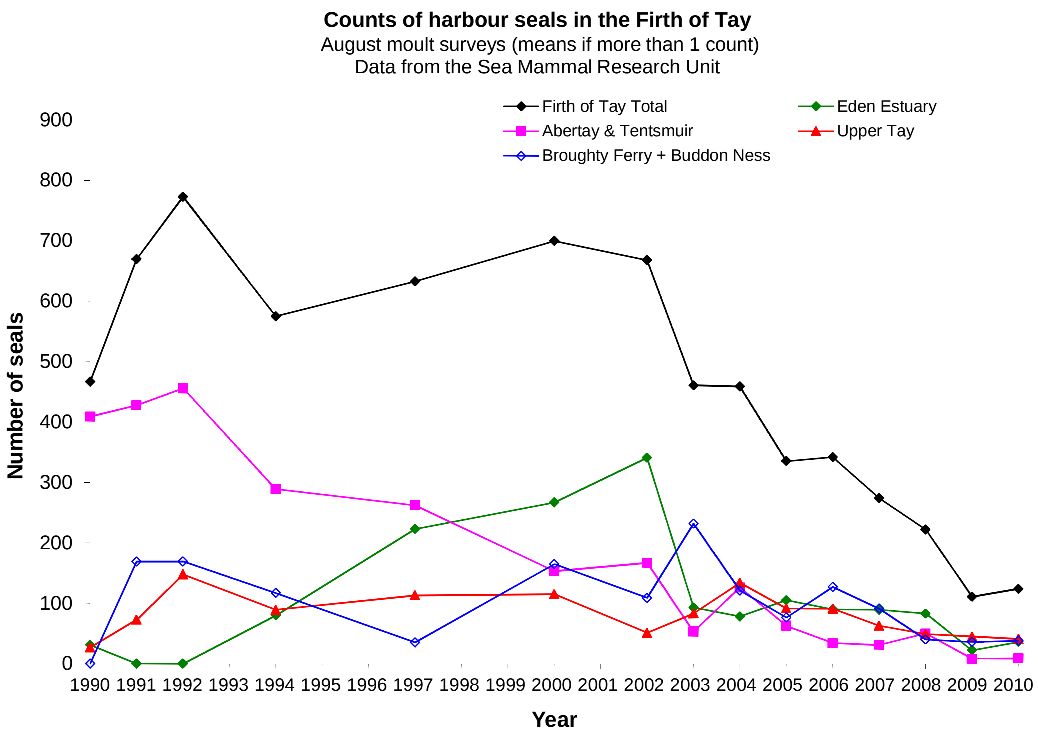


Figure 10. Counts of harbour seals in The Wash in August, 1967 - 2010. These data are an index of the population size through time. Fitted lines are exponential growth curves (growth rates given in text) with a 2^{nd} order polynomial for post-2002 counts for illustration.

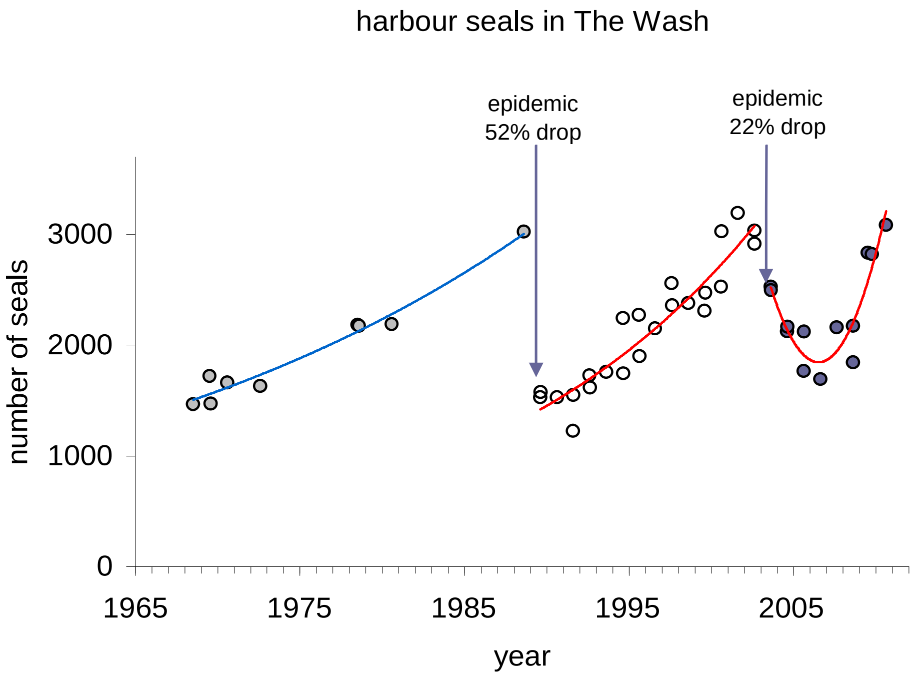


Table 1. Minimum estimates of the UK harbour seal population in Management Areas from the most recent surveys and from two previous surveys. The year of survey is underneath the number of seals counted. These are the numbers of seals counted in aerial surveys.

Harbour seal Management Area	**Current estimate** (2007-2010)	**Previous estimate** (2000-2005)	**Earlier estimate** (1996-1997)
Shetland	**3,003** 2009	**4,883** 2001	**5,991** 1997
Orkney	**2,688** 2010	**7,752** 2001	**8,523** 1997
Highland North coast	**112** 2008	**174** 2005	**265** 1997
Outer Hebrides	**1,804** 2008	**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)	**5,834** 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	**241** 2007, 2010	**406** 2005	**648** 1997
East Scotland,Moray Firth (widest) Fraserburgh to Duncansby Head	**1,114** 2007, 2010	**959** 2005	**1429** 1997
TOTAL SCOTLAND	**20,474**	**28,812**	**29,532**
	(2010)	(2005)	(1997)
Blakeney Point	**391**	**709**	**311**
The Wash	**3,086**	**1,946**	**2,461**
Donna Nook	**176**	**421**	**251**
Scroby Sands	**201**	**57** 2004	**65**
Other east coast sites	**347**	**153** 1994-2003	**137** 1994 –1997
South and west England(estimated)	**20**	**20**	**15**
TOTAL ENGLAND	**4,221**	**3,306**	**3,240**
TOTAL BRITAIN	**24,695**	**32,118**	**32,772**
TOTAL NORTHERN IRELAND	**1,248** 2002	**1,248** 2002	
TOTAL BRITAIN&N. IRELAND	**25,943**	**33,366**	
TOTALREPUBLIC OF IRELAND	**2,905** 2003	**2,905** 2003	
TOTAL GREAT BRITAIN&IRELAND	**28,848**	**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.

3 Location	07 Aug 1992	30 July 1993	13 Aug 1994	15 Aug 1997	11 Aug 2000	11 Aug 2002	7 Aug 2003	10 Aug 2004	13 Aug 2004	8 Aug 2005	9 Aug 2005	16 Aug 2005	18 Aug 2005	4 Aug 2006	20 Aug 2006	15 Aug 2007	24 Aug 2007	13 Aug 2008	20 Aug 2008	6 Aug 2009	18 Aug 2010
Survey type	fw	ti	fw	ti	fw	ti	fw	fw	fw	fw	fw	fw	ti	ti	fw	ti	fw	ti	fw	fw	fw
Ardersier	154	-	221	234	191	110	205	172	232	260	143	195	224	210	184	150	173	167	123	277	362
Beauly Firth	220	-	203	219	204	66	151	175	180	119	169	-	94	174	178	115	170	165	135	85	140
Cromarty Firth	41	-	95	95	38	42	113	90	86	98	101	-	118	119	93	67	118	90	90	90	140
Dornoch Firth (SAC)	662	-	542	593	405	220	290	199	262	199	118	-	256	249	264	153	209	160	130	166	219
***3.1* Inner Moray Firth Total**	**1077**	**-**	**1061**	**1141**	**838**	**438**	**759**	**636**	**760**	**676**	**531**	**-**	**692**	**752**	**719**	**485**	**670**	**582**	**478**	**618**	**861**
Findhorn	-	-	*58*	*46*	*111*	*144*	*167*	*0*	*98*	*90*	*58*	*148*	*74*	*63*	*68*	*82*	*94*	*69*	*115*	*73*	*123*
Loch Fleet	-	*16*		*27*	*33*	*62*	*56*	*58*	*70*	*68*	*70*	-	*76*	*79*	*53*	*85*	*87*	*87*	*77*	*65*	*114*
Loch Fleet to Dunbeath	-	*92*		*214*		*188*	-	-	-	-	-	-	*113*	*163*	*137*		*90*	*102*	*43*	*19*	*101*
Outer Moray Firth Total				**1428**		**832**							**955**	**1057**	**989**		**941**	**840**	**713**	**775**	**1199**

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.

4 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	8 Aug 2005	9 Aug 2005	14 Aug 2005	14 Aug 2006	4 Aug 2007	7 Aug 2007	29 Aug 2008	7 Aug 2009	16 Aug 2010
Survey type	fw	fw	fw	fw	ti	fw	fw	fw	fw	fw	fw	ti	fw	fw	ti	fw	fw	fw
Eden Estuary	31	0	0	80	223	267	341	93	78	81	95	139	90	99	79	83	22	36
Abertay & Tentsmuir	409	428	456	289	262	153	167	53	126	80	26	82	34	32	30	50	8	9
Upper Tay	27	73	148	89	113	115	51	83	134	90	80	104	91	62	64	49	45	41
Broughty Ferry & Buddon Ness	0	169	169	117	35	165	(109)	232	121	68	125	36.	127	68	114	40	36	38
***4.1* Firth of Tay Total (SAC)**	**-**	**670**	**773**	**575**	**633**	**700**	**(668)**	**461***	**459**	**319**	**326**	**361**	**342**	**261**	**287**	**222**	**111**	**124**

[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;s**ee 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**
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
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[6]
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
Scroby Sands	-	- -	-	- -	- -	-	61 -	- 49	51	58 72	52 -	69 74	84 9	75			49 64		71		60 101	100 230	219 183
The Tees	-	- -	-	- -	- -	-	- 35	- -	-	- -	- -	- -	- -	-	-		- -	-	-		41[3]	49[4]	53[5]
Holy Is, Northumb	-	- -	-	- -	- -	-	13	- -	-	12[2]	- -	- -	10	-	-		- -	17[2]	-	7			
Essex, Suffolk& Kent	-	- -	-	- -	- -	-	- -	90 -	-	- -	- -	- -	- -	-	- 72	190	- -	101	-		299		

[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).
[4]Tees data kindly provided by Robert Woods, INCA (Woods, 2009).[5]Tees data kindly provided by Robert Woods, INCA (Woods, 2010).
[6]Possible disturbance due to cockle fishery.

Dave Thompson

Distribution and abundance of harbour seals (Phoca vitulina) during the breeding season in the Wash. 2001 to 2010.

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Background

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

In the summer of 1988 an epidemic of phocine distemper virus (PDV) spread through the European harbour seal population. More than 18000 seal carcasses were washed ashore over a 5 month period, many of them in areas with high levels of human activity (Dietz, Heide-Jorgensen & Härkönen, 1989). Mortality in the worst affected populations, in the Kattegat-Skagerrak, was estimated to be around 60% (Heide-Jorgensen & Härkönen, 1992). After the end of 1988, no more cases of the disease were observed until the summer of 2002, when another epidemic broke out (Harding *et al.*, 2002). Mortality in the European population during the 2002 epidemic was 47%, similar to that seen in 1988 (Harkonnen et al. submitted). However, on the English East coast the mortality rate estimated from pre and post epidemic air survey counts was much lower, approximately 22% (Thompson, Lonergan & Duck, 2005). The pre-epidemic population in 2002 was similar in size to the pre-epidemic population in 1988 and the disease hit the English population at the same time of year, so to date there is no clear explanation for the lower mortality rate.

In general, harbour seal population monitoring programmes have been designed to track and detect medium to long-term changes in population size. As it is difficult to estimate absolute abundance, monitoring programmes have usually been directed towards obtaining indices of population size. If consistent, such time series are sufficient to describe populations' dynamics and have been used to track the long-term status of the English harbour seal population. However, these indices are based on the numbers of individuals observed hauled out, so their utility depends on this being constant over time and unaffected by any changes in population density or structure.
Counts are usually carried out during the annual moult, when the highest and most stable numbers of seals haulout. Unfortunately such counts do not provide a sensitive index of current population health. It is generally accepted that breeding success is a more sensitive index. The breeding season is also the time when disturbance of seal haulout groups is likely to have direct effects. E.g. disturbance of mother/pup pairs will lead to temporary separation which may have direct effects on pup survival, especially if the disturbance is repeated.

Most of the UK harbour seal population breeds on rocky shore habitats, where identifying and counting pups is both difficult and expensive. However, on the English east coast harbour seals breed on open sand banks where pups are relatively easy to observe and count. As a first step towards improving the monitoring program (to increase its sensitivity to short term changes), we identified a need for a baseline survey to map the distribution of breeding harbour seals. In June 2001 Fenland District Council commissioned Sea Mammal Research Unit to conduct an aerial survey of the entire breeding population in the Wash. Since 2004 Natural England have commissioned single annual breeding season surveys to develop a time series of pup counts as an adjunct to the annual moult surveys to obtain a more sensitive index of current status as well as to monitor the distribution of breeding seals. These counts are conducted at the end of June or beginning of July when the peak counts are expected. In 2008 additional funds were provided to obtain a time series of counts within one breeding season to define the parameters of the pupping curve. In addition to confirming the date of the peak number of pups ashore and available to be counted, these results will provide an estimate of the ratio between peak pup counts and pup production and provide an indication of the likely error on estimates of pup production.

Historical data

One or two complete surveys of the Wash were carried out during the moult, in the first half of August in each year from 1988 to present. The results, combined with counts at the same time of year from the period 1968-2007 are shown in fig. 1. The counts increased between the late 1960s and 1988, at an average of 3.4% pa (R^2=0.62, p<<0.0001). The 1988 count was obtained approximately one week before the first reports of sick and dead seals being washed up on the UK coast. The number hauling out fell by approximately 50% between 1988 and 1989, coincident with the PDV epidemic. After 1989 the number increased again, at an average of 5.9% pa (R^2=0.77, p<<0.0001). The post epidemic rate of increase was significantly higher than the pre epidemic rate (t=2.87, df=20, p<0.01 (Comparison of regression coefficients for small samples with unequal residual variances (Bailey 1972)).

Post epidemic counts were also obtained at the other major east coast haulouts outside the Wash, at Blakeney (45km east) and Donna Nook (40km north). At both sites the counts fell after 1988, reaching a minimum in 1990 (fig 2). Between 1990 and 2001 Blakeney counts increased by an average of 14.4% pa. (R^2=0.47, p<0.01), and DonnaNook counts by 18% pa (R^2=0.35, p<0.03). The total for all three east coast sites increased at an average rate of 7.2% pa. (R^2=0.87, p<<0.0001) (fig 2).

In 2002 there was another outbreak of PDV. The timing of the epidemic and the population size were similar to 1988. The population in the Wash declined by an estimated 22% based on results of surveys in 2003 and on a fitted population growth model (Thompson, Duck & Lonergan, 2005). There appears to have been a continued decline or at least a failure to recover in the moult counts for the English east coast population. Overall, the combined count during the moult for the English East coast population in 2006 was 12% lower than the mean count in 2005, although preliminary results from the 2008 moult count are similar to the 2005 level. This apparent lack of recovery or continued decline contrasts with the rapid recovery of the Wadden Sea population that has been increasing at around 12% p.a. since 2002. This failure to recover from the 2002 epidemic is a cause for concern and should be investigated.

In 2010 a drilling barge was positioned on the eastern side of the mouth of the river Nene. Although the barge was positioned away from the low water channels and therefore thought unlikely to have any effect on haulout behaviour there were some concerns over the potential disturbance due to hovercraft operations that would pass within 200m of hauled out seals. As these operations would continue through the pupping season, the pup counts would allow us to investigate the level of disturbance through the pattern of haulout use at nearby haulout sites.

Breeding season surveys 2004 to 2010

Based on a preliminary assumption that the peak number of pups would be encountered at the end of June, beginning of July we have surveyed the breeding population between 27th June and 4th July in each year from 2004 to 2010. In addition in both 2008 and 2010 we carried out four additional surveys between 12th June and 13th July to establish the form of the pups ashore curve. Surveys were carried out over the period 1.5 hours before to 2 hours after low water. All tidal sand banks and all creeks accessible to seals were examined visually. All groups of more than 10 animals were photographed using either colour reversal film in a vertically mounted 5X4" format, image motion compensated camera in 2004 & 2005 or with a hand held digital SLR camera since . The equipment and techniques are described in detail in Hiby, Thompson & Ward (1986) and Thompson et al. (2005). Photographs were processed and all seals were identified to species. Harbour seals were then classified as either pups or 1+ age class. No attempt was made to further differentiate the 1+ age class

Pup Birth and Haulout models

A model relating the expected numbers of pups on the banks to the birth curve and haulout patterns is currently under development. The model will use data from the 2008 and 2010 surveys of The Wash and 2006 to 2010 surveys of the Moray Firth for which we have comparable series of aerial survey pup counts throughout the breeding season. It will also incorporate data from both the Dutch Wadden Sea and Sable Island, Canada. Here we present the raw data from the Wash surveys. .

RESULTS

The peak count in 2010 occurred on the 3rd July when a total of 1431 pups and 3702 older seals (1+ age classes) were counted in the Wash. No pups were observed at either Donna Nook or at Blakeney point, the two nearest haulout sites to the North and East of the Wash respectively. This peak count compares with peak counts of 1130 pups and 2523 older seals (1+ age classes) during the 2009 breeding season survey and 994 pups and 2132 older seals (1+ age classes) during the 2008 breeding season survey. Previous counts are presented in table 1. These were distributed over 48 separate haulout groups, although the number of sites is to some extent a function of the arbitrary division or pooling of groups. Figure 3 shows the distribution of haulout sites in the Wash and the counts of seals at each site obtained during the 2001, 2004, 2007 and 2010 breeding seasons. For 2010 only the peak count survey data are shown. Pups were widely distributed throughout the Wash, being present at all but two of the occupied sites in all years between 2004 and 2010.

The 2010 survey produced the highest pup count ever obtained in the Wash, 26% higher than the estimated peak in 2009 which was itself 13.6% higher than the 2008 peak count. The 2010 count was approximately 40% higher than the average peak count for 2006 to 2008. . Figure 4 suggests that the data may indicate a continual increase in pup production of approximately 11% p.a. since 2001. However, the trend could also be adequately described by two step increases one around 2005-2006 and another in 2009 2010. The maximum adult count in 2010 was 40% higher than the equivalent count in 2009. However, there is no clear pattern in the non pup count over the last 5 years.

Differences in timing of surveys (see later) mean that direct comparisons are problematic, but the evolving time series is indicating that there was no evidence of a major decline in pup production after the 2002 PDV epidemic. The large increase from 2008 to 2009 and the even larger increase between 2009 and 2010 mean that the time series is now fairly well represented by a simple exponential increase of 11% p.a.. The apparent step increase in 2006 may have been simply part of an overall increasing trend in pup production in the Wash. This increase in pup production contrasts with the apparent lack of an increase in the moult counts between 2003 and 2009 (figs 1 & 4). Figure 1 shows that the moult count has shown no clear trend since the 2002 epidemic Although the higher counts in 2009 and 2010 may indicate the start of a recovery.

The distribution of pups was relatively constant over the period 2001 to 2005 when pooled into the four sub-regions the overall geographical spread was similar (fig 5). Almost all of the increase in pup counts and therefore presumably also pup production in 2006 and subsequent years occurred in the eastern half of the Wash, from the mouth of the Nene eastwards. In 2001 only one pup was seen in the Western region of The Wash. By 2004 around 5% of total pup production was found on these outer western banks, in 2005 this had further increased to 9%. However, these numbers are low and the number of pups counted in the western region has remained reasonably constant since 2006.

Five surveys were carried out in both 2008 and 2010 providing five counts at approximately weekly intervals (fig 6). As a preliminary step, a cubic polynomial was fitted through the data to obtain an approximate estimate the time of the peak count. The data suggest that the peak number of pups occurred on 28th or 29th June in 2008. A similar cubic polynomial was a poor fit to the 2010 data. For the purposes of estimating peak count dates we fitted a simple smoothed line. This indicates that the peak pupping date occurred between 26th June and 3rd July, most likely on 1st July. The plot suggests that counts between 23rd June and 3rd July in 2008 would have been within 5% of the maximum and counts between 27th June and 4th July in 2010 would have been within 5% of the maximum. All surveys since 2001 have been carried out during the window 27th June to 4th July meaning that peak counts can be reasonably compared across years.

Discussion

The most significant event in recent years for harbour seals in the Wash was the recurrence of a PDV epidemic in 2002. Our standard annual moult surveys indicated that the effect of this epidemic were less severe than in 1988. There was still a significant reduction of 22% in our population index, so we might expect a commensurate decrease in pup production. However, if there were differential sex and/or age linked mortality, the effects of the epidemic on the dynamics of the population could be more or less severe than expected. Unfortunately the moult counts cannot differentiate the population into sex or age classes, and there was little information on the sex and age structure of the seals found dead in 2002.

Although the standard moult counts provide a robust index of population size, it is somewhat damped and will therefore not be a particularly sensitive indicator of current status of the population. Pup production can be thought of as a compound of population size and fecundity and may therefore give a more sensitive index of population status.

The recent low intensity pup survey effort has produced two interesting results that highlight the advantage of a two pronged approach to seal monitoring. Although there was a well documented decline of over 20% in the population as a result of the 2002 PDV epidemic there was no apparent decrease in pup production between the pre and post epidemic counts. There are several potential explanations for the lack of a decline. If there was differential mortality, the number of adult females lost to the epidemic may have been small. Alternatively any decrease in adult female population could have been masked by variations in fecundity. Alternative scenarios involving temporary immigration are thought to be less most likely.

The most recent data suggest that the apparently dramatic step change in pup production between between 2005 and 2006 may have simply been part of a continuing increasing trend. The large increase in pup count in 2006 was unexpected and hard to explain, but has been maintained into 2007-2010. Although the moult counts in Wash continued to decline after the 2002 epidemic they have now clearly stabilised and are showing signs of a rapid recovery.

As we are conducting only single counts in most years there is a potential danger of confusing timing effects with actual changes. Therefore, before attempting to draw conclusions about the causes or implications of changes in pup production it is important that we are able to discount the possibility that the difference in counts were artefact of the changes in timing of the surveys.

The timing of the 2004 surveys was constrained by aircraft and staff availability, and the count in 2004 was approximately 12 days later than in 2001. Although we have no hard information, local observers suggested that the number of pups might decline in early July as pups wean and/or begin to spend time foraging with their mothers. We would therefore expect the 2004 count to represent the same or a lower proportion of the pup production compared to the 2001 count. The 2004 pup count was in fact 12% higher than the pre-epidemic count. As a result, we carried out the 2005 count midway between the 2001 and 2004 count dates. The pup count increased slightly between the 2004 and 2005 counts. Assuming that this indicated that the surveys were occurring around the peak, we carried out the 2006 count midway between the dates of the 2004 and 2005 flights. The 2007 peak count was timed to coincide with the date of the 2006 survey.

In 2008 and 2010 we carried out a sequence of surveys to confirm the timing of the peak. The peak number ashore occurred on or about the 28th June and on or about 1st July, confirming that the previous years' counts had been close to the peak. In fact, with the exception of 2001 and 2004, all counts would have been within 4% of the peak if the timing in each year was similar to the 2008 or 2010 patterns. The largest under-estimation would have been in 2001 when the count would have represented 90% of the peak if the timing was the same as in 2008.

The series of pup counts from 2008 and 2010 confirms the timing of the peak count and will allow estimation of the shape and therefore the cumulative total of the birth curve. This confirms that a pup-production monitoring program based on single annual counts with occasional more intensive surveys, (e.g. every 5 years a series of 4 or 5 surveys to re-estimate birth curve parameters) will provide data to be combined with the annual total population index surveys in August to allow more responsive and sensitive management of the harbour seal population.

The observed large increase in pup production in the absence of an equivalent increase in the moult counts is unexplained at present. It could be generated in various ways:

1. Immigration of a large number of adult females. The absence of any substantial populations on the east coast means that the source of seals would have to be either the Wadden Sea or the Scottish East coast. Data on seal movements suggest that immigration from Scotland is unlikely.
2. A continual increase in fecundity. This seems unlikely given the scale of the increase since 2005

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

The results of the 2001 pup survey suggested that there had been a significant shift in spatial distribution of breeding seals over the preceding 30 years. The 2004 and 2005 distribution was similar to the 2001 distribution, suggesting that there has been a real shift in distribution with a much higher proportion of pups being found along the banks of the creeks along the southern edge of the Wash, mostly inside the RAF Danger area. The proportional increase in the inner Wash coincided with a dramatic reduction in the relative importance of the banks along the western edge of the Wash, although this difference may be decreasing. The main increase in 2006 to 2010 was on banks in the east of the Wash.

Data from the breeding surveys suggest that the hovercraft activities in the Wash in summer 2010 did not unduly disturb harbour seals close to the route. The two haulout sites nearest to the hovercraft route were both occupied on all surveys and both had substantial numbers of pups (Fig 7). One group was as close as possible to the barge and must have been passed regularly by the hovercraft. Again there was no indication that seals had been disturbed by the close approaches of the hovercraft or had been prevented from hauling out or pupping in close proximity of the barge. Although we know little about haulout site fidelity in harbour seals in the Wash, it is clear that several apparently suitable alternative haulout and/or pupping sites were easily accessible. The fact that seals continued to use the closest sites is a strong indication that there was no significant disturbance effect. It is therefore extremely unlikely that they would have had a detrimental effect on the wider population.

In conclusion, these single annual surveys supplemented by occasional multi survey programmes to establish the timing of breeding give us an appropriately accurate estimate of total pup production, the data do indicate that:

1) The breeding population, or at least the pup production was not dramatically reduced by the 2002 PDV epidemic;
2) Therefore, mortality on breeding females and recruiting females was probably not higher than the population average;
3) The pup production has not followed the decrease and later stabilisation in moult counts and has in fact grown by 11% pa since 2002;
4) A single series of multiple pup counts within one season allows us to estimate the pup production in years with only a single count around the peak pupping dates, and will provide confidence intervals on the pup production estimates.
5) There is no evidence that the position of the drilling barge or the activities of the hovercraft had any effect on seal haulout patterns.

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

year	*2001*	*2004*	*2005*	*2006*	*2007*	*2008*	*2009*	*2010*
pups	*548*	*613*	*651*	*1054*	*984*	*994*	*1130*	*1432*
Non pups	*1802*	*1766*	*1699*	*2381*	*2253*	*2009*	*2523*	*3702*

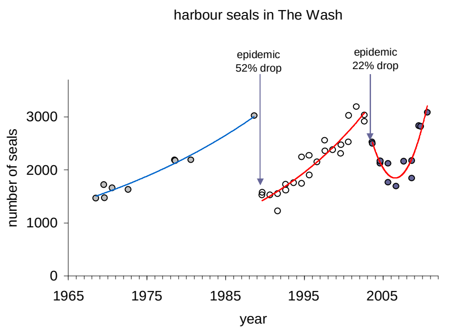

Figure 1. Moult counts of Wash harbour seal population between 1966 and 2010.

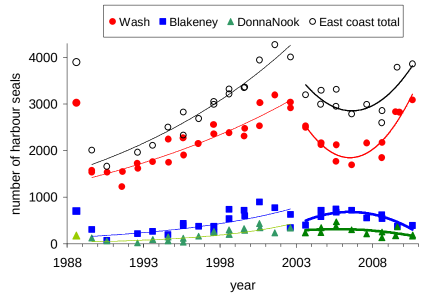

Figure 2. Moult counts of the Wash, Donna Nook and Blakeney harbour seal population between 1988 and 2010.

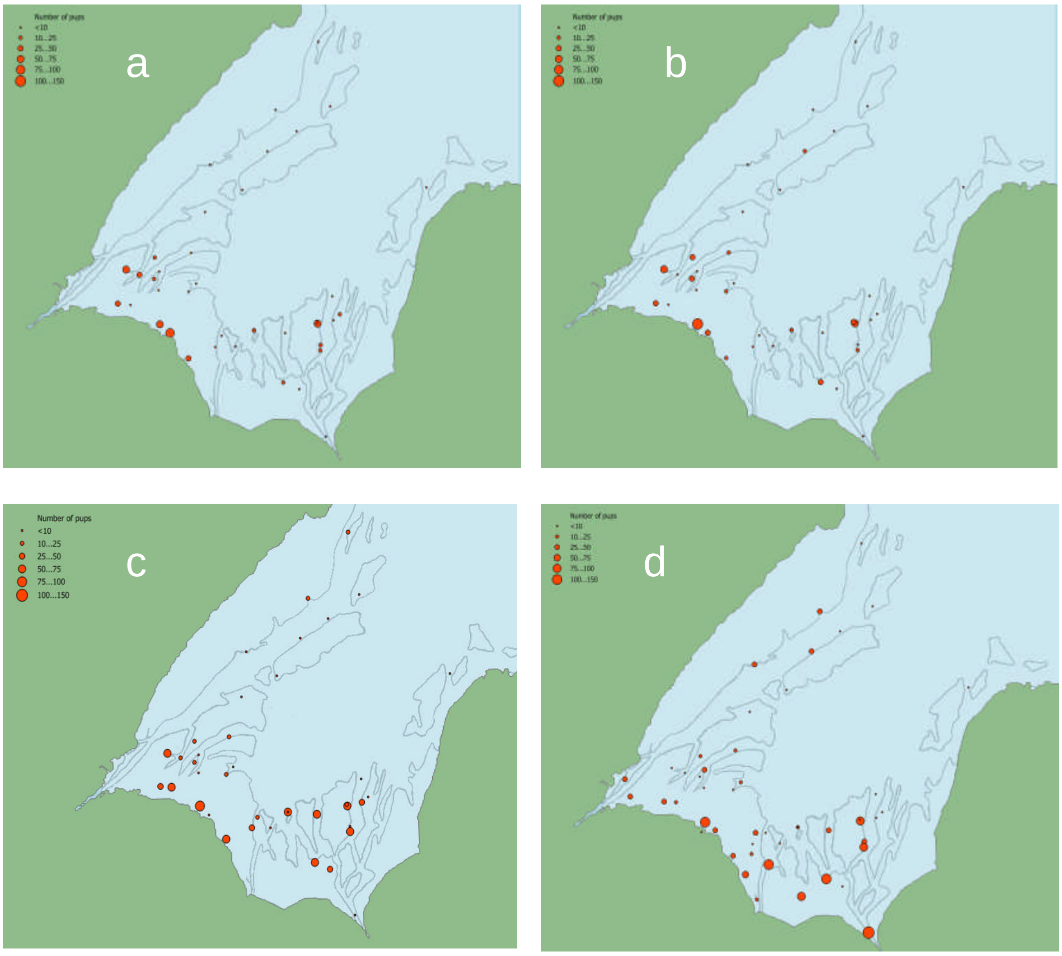

Figure 3. Distribution of pups in the Wash, a) 2001; b)2004; c)2007; d)2010;. Numbers of pups are represented by the areas of the circles on each site. Locations given to nearest 500m. Maps for 2010 shows the distribution of pups on the day with the maximum count.

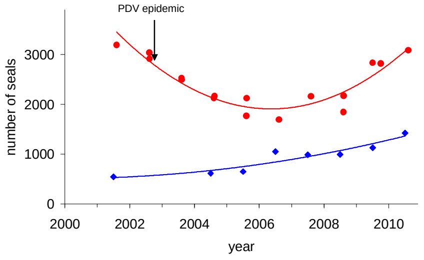

Figure 4. Maximum counts of pups in The Wash between 2001 and 2010 together with the standard moult population monitoring counts for the same sites. The fitted line for the pups is a simple exponential and a simple quadratic has been fitted to the moult count data to illustrate the general trend.

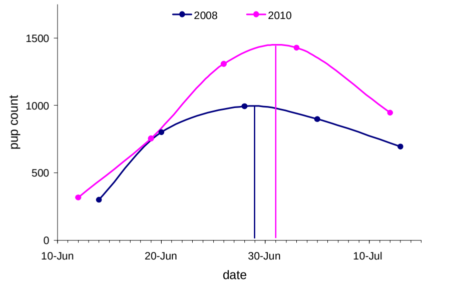

Figure 6 Counts of harbour seal pups in The Wash during the 2008 and 2010 breeding seasons. The simple smoothed lines suggest the peak number of seals ashore probably occurred on the 28th or 29th June in 2008 and on or about the 1st July in 2010.

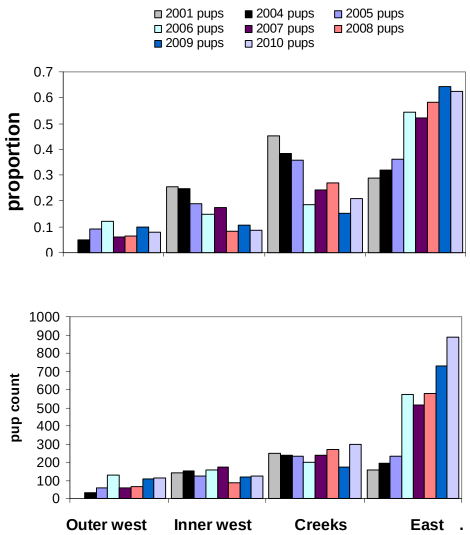

Figure 5. Distribution of harbour seal pups in the Wash during the 2001 & 2004,- 2010 breeding seasons pooled into geographical sub regions(Vaughan, 1978) Note the sudden increase in numbers of pups in the complex of banks in the south east corner of the Wash in 2006. This was maintained through to 2010.

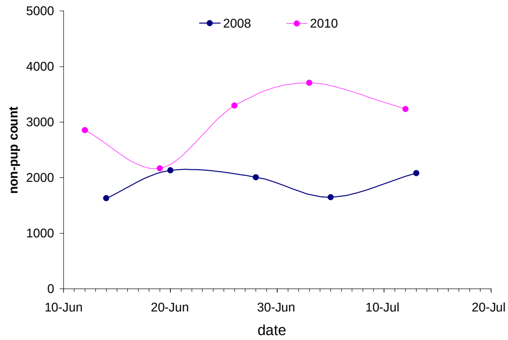

Figure 7 Counts of non pup (aged 1 and older) harbour seals in The Wash during the 2008 and 2010 breeding seasons. The wide variation in counts in 2010 indicates that breeding season counts would provide a less robust index of population size.

INDIVIDUAL-BASED APPROACHES TO UNDERSTANDING HARBOUR SEAL POPULATION DYNAMICS

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Summary

Population-level studies are crucial for monitoring species abundance and distribution, but it is widely recognized that individual-based studies offer the greatest insights into the drivers of population change[1]. A lack of such studies has constrained understanding of harbour seal population dynamics across their global range, and currently limits our ability to manage widespread declines of this species in Scotland [2]. The development of a new harbor seal breeding site has offered an opportunity to develop an individual based study of this species in NE Scotland. This briefing paper provides an overview of the study, highlights key findings from a recent PhD study carried out at this site, and discusses future research opportunities.

Study population

Since 1995, harbor seal abundance in the Moray Firth's Dornoch Firth SAC has declined, but there has been a steady increase in the number of animals breeding nearby in Loch Fleet NNR[3] (Fig. 1).

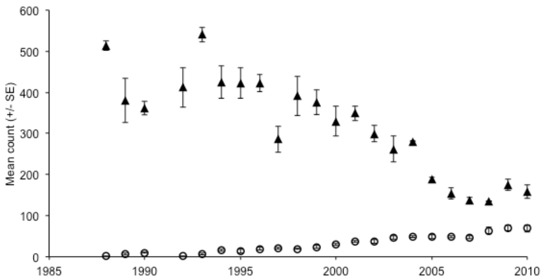

Fig. 1. Trends in mean pupping season counts of harbor seals in the Dornoch Firth SAC and Loch Fleet NNR. Adapted from data in Ref 3 using additional unpub data from SMRU.

The Loch Fleet breeding site is easily observable, and provides excellent opportunities for identifying individuals using photography. Following a successful pilot study in 2006[4], individual-based studies have continued during each breeding season and, in 2008 and 2009, were conducted throughout the year. During this period, 347 photo-ID surveys have resulted in the identification of >150 unique individuals, including 74 confirmed females and 41 males. Individuals exhibited a high degree of site fidelity, with almost 80% of females seen in all 5 years and 74% of males seen in at least 4 years.

Key Findings

1. Abundance & haul-out probability

Mark-resight models[5] were used to estimate seasonal variation in the number of seals using Loch Fleet from data collected throughout 2008 and 2009 (Fig. 2). These observations also demonstrated that >75% of individuals using the site during the breeding season were also observed in Loch Fleet at other times of year.

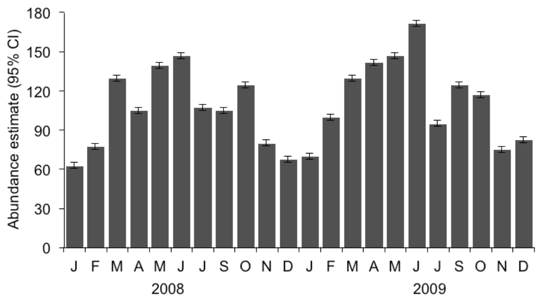

Fig. 2. Monthly estimates of the abundance of harbor seals in Loch Fleet based upon mark-resight models.

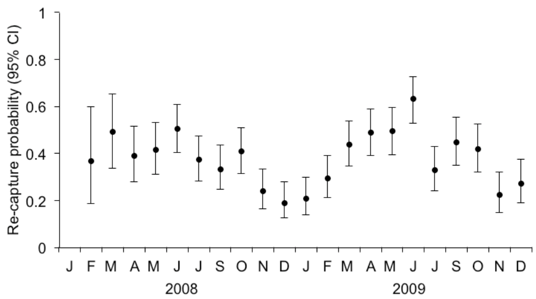

Fig. 3. Estimates of re-capture probability from mark-resight models; a proxy of seasonal variation in haul-out frequency.

2. Phenology & pup production

In 2006, daily observations of individually recognizable females in Loch Fleet provided the first direct estimates of pupping date for any European harbor seal population[4]. Subsequent work has demonstrated significant inter-annual variation in the timing of pupping, at both the population and individual level, with the annual median pupping data varying between the 13th and 19th June. Suggestions that variation in the timing of pupping provides a useful indicator of environmental change[6] are supported by a significant relationship between median annual birth date and the mean lactation duration (Fig. 4). However, there was no relationship between median pupping date and the date of maximum pup counts as assumed in phenological studies in the Wadden Sea[6].

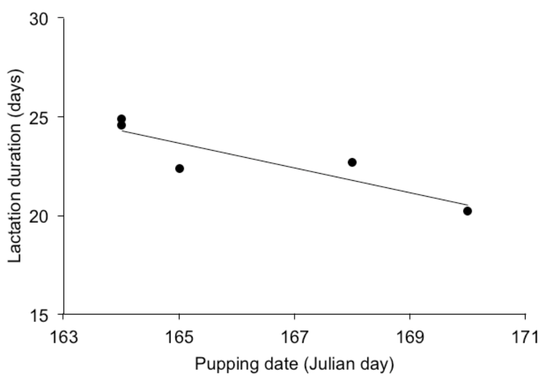

Fig 4. Relationship between median pupping and mean duration of lactation for each year.

3. Survival

Data from 2006-2010 were used to model sex-specific survival rates using a multi-state model that accounted for sex not always being known (Table 1). These data were all collected after the introduction of the Moray Firth Seal Management Plan, and these survival estimates are therefore likely to represent values in the absence of significant mortality from shooting.

4. Fecundity

Not all pups will be detected at inter-tidal sites. Fecundity was therefore estimated using a closed robust design multi-state model with misclassification. The best supported model produced a fecundity estimate of 0.83. Based upon repeated observations of individual females in different years, the maximum inter-birth interval was one year.

Table 1. Photo-ID based estimates of harbor seal survival.

Parameter		Estimate	95% CI
Survival	Male	0.89	0.71 – 0.96
	Female	0.97	0.90 – 0.99
	Unknown Sex	0.95	0.88 – 0.98
Recapture	Male	1.00	1.00 – 1.00
	Female	0.98	0.91 – 1.00
	Unknown Sex	0.84	0.71 – 0.91

Future Research

Sites suitable for individual based photo-ID studies of harbor seals are rare, and we know of no other site worldwide that offers such easy access and high re-capture rates. Collaboration with SMRU demonstrated that these individuals can be captured to collect data on key individual co-variates[3], thereby permitting assessments of the reproductive and survival consequences of variation in these factors. Loch Fleet's proximity to proposed offshore windfarms also provides unique potential for assessing individual and population consequences of acoustic disturbance. Given the high scientific and policy value of the site, the development of this individual based study is now a key strategic goal for the Lighthouse Field Station.

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An estimate of the size of the British grey seal population based on summer haulout counts and telemetry data.

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1. **Summary**

Scaling up from a count of hauled out seals to a population estimate requires allowance to be made for the proportion of animals at sea, and therefore unobserved, during the survey. We used historical telemetry data to assess the effects of age and sex on the proportion of British grey seals hauled out around August daytime low waters, and combined this with counts of grey seals made during the 2007-9 harbour seal moult surveys to estimate the total UK population of grey seals at that time as 88,300 (95% confidence interval: 75,400 – 105,700). Seals of different ages and sizes hauled out for similar proportions of this time. This suggests that classifying images of individual animals by age and sex will not greatly improve population estimates based on counts of hauled out animals.

2. Introduction

British grey seal numbers are currently estimated by using Bayesian State Space models to scale up from pup production to population estimates. These models produce very different population estimates depending on where in the lifecycle density dependence is assumed to operate (Thomas 2010; Lonergan *et al.* 2010). Unfortunately the pup production data provide very little information for selecting between different models. Counts of hauled out grey seals were therefore carried out during the summer harbour seal moult surveys. This briefing paper investigates the proportion of grey seals hauled out, and therefore available to be observed during the surveys, and uses these proportions to scale the counts up to population estimates with appropriate confidence intervals. It also considers the variability of the haulout behaviour and the effect this could have on these results.

Specifically, we examine environmental and regional differences in the proportion of time around low tides that grey seals haul out for. We also look at how sex and length, which correlates with age (at least among younger animals), affect the probability of their being hauled out during the surveys.

Last year, we reported that overall, the animals hauled out for approximately 0.35 (95% CI: 0.32-0.38) of the time considered, and, while there was wide individual variation, neither sex nor length had a significant effect. It therefore seemed that unclassified census counts are sufficient for population estimation. We also found that neither the region nor the exact timing of the survey within the summer had a substantial impact on the probability of being hauled out (Lonergan *et al*. 2009).

While the previous results were broadly correct, those confidence intervals were for the proportion of time animals hauled out. We have improved our summarisation of the telemetry data, increasing the amount of information obtained from it, and also corrected a bias that was introduced by our treatment of missing data. In this paper we give revised estimates of the expected proportion of animals observed during surveys and the variability of survey results. We apply these to generate explicit regional population estimates and appropriate confidence intervals.

3. Methods

Aerial Survey data

In August 2007, 2008 and 2009 the harbour seal moult surveys were extended so that, between them, they covered almost all potential grey seal haulout sites in Great Britain. These aerial survey flights were carried out between 08:00h and 18:00h and within two hours of a local low water that fell within the same window. On rocky shores in Scotland the surveys were further restricted to afternoon tides. The data were aggregated into five regions (North Sea, Orkney, Inner Hebrides, Outer Hebrides, and Shetland – the first four of these corresponding to regions used for population estimation).

Telemetry Data

All the telemetry data that have been collected from British grey seals over the past 20 years were examined. Only information collected within the August aerial survey windows was used for this analysis. This came from 107 animals, tagged between 1995 to 2008 (table 1), and described a total of 6,400 hours of relevant animal behaviour, 98% of the total that complete knowledge of these individuals would have provided. The remainder of the information had been lost or corrupted during transmission.

Individual data

Each individual animal was handled to attach its tag. At this time its sex, mass and length were recorded and an individual identifier chosen. A small proportion of this information has subsequently been lost. Animals caught before they had left their natal beach, and some small individuals were recorded as juveniles, but accurate aging of seals beyond the first few months of life requires examining growth layers within an extracted tooth. Teeth were not generally extracted, and animals' weights can vary seasonally, so we use length as a proxy for animals' ages.

Environmental data

The location information provided by the tags was used to associate seals with haulout sites, named areas approximately 10km across. Each animal was linked with a series of sites, with time at sea being associated with the haulout site at which the animal had last been recorded Each haulout site was also associated with the nearest Secondary Tidal Prediction Port. From this we calculated the timing and height above datum of the low waters the animals experienced. Since the tidal range varies between areas, we used the minimum number of days from full or new moon to represent the Spring-Neap tidal cycle and called this "neapiness". Daily rainfall, wind speed, and mean temperatures were obtained from nearby meteorological stations and associated with the haulout sites. The haulout sites were grouped into the regions. There was no telemetry data associated with haulouts in Shetland, but additional data was available from the small grey seal populations in the Irish Sea, an area that was not covered by these aerial surveys.

Haulout information

The tags have a conductivity sensor to determine whether they are wet or dry. They record haulouts, defined to start when the tag is continuously dry for 10 minutes and end when it is continuously wet for 40 seconds. Haulouts are numbered consecutively by the tags, enabling animals to be classified as hauled out, not hauled out, or of unknown status at particular times. The pseudo-random ordering and delayed transmission of the data mean that the probability of data being missing is unlikely to be related to seal behaviour (Fedak et al., 2002). Unfortunately, transmitting the data as haulout records biases the recovered information on the proportion of time animals haul out, since the two at-sea periods around any missing haulout record will also be classified as of unknown status. To remove this bias we treated the status of the first haulout period after each block of missing data as unknown. We then calculated the proportion, out of the time within each survey window that its status was known, that each animal was hauled out.

This process resulted in a set of 1824 datapoints, each one of which contained an estimate of the proportion of one potential tidal survey window that one animal hauled out, the date and time of that low tide, its height, the region and local haulout site at which it occurred, and the animal's identifier. Most datapoints also contained the animal's length and sex as well as the temperature, rainfall and wind speed for that day and place.

Analysis

The analysis occurred in four phases: first the effects of the various potential explanatory factors were examined; then the independence of the behaviour of animals was assessed to examine the effects of unmeasured covariates and the effective sample sizes; next the distribution of appropriate bootstrap resamples of the haulout data was generated; and finally the aerial survey data were multiplied by this to give an overall population estimate.

Mean proportions of animals hauled out, and standard errors around these estimates, were calculated and plotted by day of year, year, region, the height of low tide above datum, neapiness, mean daily temperature and daily rainfall. The proportion of time individual animals spent hauled out was also plotted out against their lengths and by sex. The Mann-Whitney U-test was used to look at differences between the sexes and between behaviour during the week and at weekends. Spearman's rank correlation coefficient was used to look at the effects of tidal height, temperature, wind speed, rainfall and animal length. To allow for ties and the non-independence of the datapoints, the results of these tests were compared to an empirical null distribution, generated by repeatedly permuting the data. The non-linear effects of time of low tide, day in year and "neapiness" were investigated by using the Wald-Wolfowitz non-parametric runs test, with data values arranged in order of the explanatory covariate. Two separate sets of empirical null distribution were created for the day of year tests. To consider temporal autocorrelation in behaviour, the ordering of the days was permuted, while cross correlation between animals was investigated by creating permuted datasets with data from each individual animal time-shifted separately.

Differences between regions were investigated by comparing the maximum differences between regional means to a distribution of equivalent values generated by repeatedly permuting the animals between regions. Similar permutations were carried out to compare years, but these had to discard years from which there was insufficient data.

A simple overall estimate of the expected proportion of the population hauled out during the survey window was calculated as the mean of the proportion of the time the individual animals were hauled out. A bootstrap estimate of the precision of this estimate was made from 10000 replicates with the animals as the unit of resampling. The validity of the resulting confidence interval depends on the independence of the data from the individual animals.

If all the datapoints were independent, and drawn from the same distribution, then a simple estimate of the expected variability in the proportion that would be seen during repeated surveys could come from repeatedly drawing sets of 107 datapoints, one for each animal included in the study, from the dataset. There are three potential problems with such an estimate. These result from: differences between the behaviour of individual animals, autocorrelation within each individual's behaviour, and correlation between the behaviour of nearby animals.

If individuals vary in the proportion of the survey windows that they haulout for, then a simple bootstrap resampling of the data is likely to underestimate the variability of real surveys. If this variability is correlated with the amount of data received from each animal, then the mean of the individual animals' mean haulout proportions will differ from a direct, unweighted, mean over the dataset..

To investigate autocorrelation in individual behaviour, which could be expected to occur given that the species typically hauls out for periods between foraging trips lasting several days, Wald-Wolfowitz runs tests were performed. Permuted versions of the data from individual animals provided null distributions for significance testing.

A simple way to deal with both variability between individuals and autocorrelation in individual behaviour is to calculate confidence intervals based on bootstrap resamples that take one datapoint from each individual. However that ignores correlation between the animals' behaviour. Substantial (positive) correlation between individuals' behaviour would make the width of this confidence interval an underestimate of the true value.

We tested for correlation between individuals using a weighted mean of the standard errors of groups of animals. We did this at the regional and local, haulout, level. In each case we divided the animals into groups, each of which contained data from one day and area. Lone animals were discarded, and the standard error (standard deviation divided by the number of animals) was calculated for the remaining groups. Since larger groups contain more data, and should therefore produce better estimates of the standard errors, we then took a weighted mean, with each datapoint weighted by the number of individuals in each group, as an overall estimate of "average standard error". We then created replicate datasets by permuting the datapoints between the groups and recalculating standard errors. The statistical significance of the correlation within the groups was estimated by comparing the original values to the distributions from the permuted datasets.

A simple bootstrap will underestimate the variability of future samples taken from a structured dataset. We therefore made estimates, for each day of the year, of the mean and standard error of the proportion of the haulout window for which the tagged animals were hauled out. We drew 1000 samples from each of a set of beta distributions, with these means and standard deviations, to approximate the overall distribution of proportions of animals that could be expected to be observed on a synoptic survey of the population carried out at some point within this period. The proportion of animals observed during a multi-day survey can be estimated by the mean of the relevant number of draws from this distribution. This was done 1000 times for each region to create bootstrap replicate estimates. The results of the aerial surveys were then divided by each estimated proportion to scale up to a distribution of population estimates. This was done separately for each region, and the results summed to give total population estimates. Confidence intervals were then calculated from these results.

4. Results

The summarised data is displayed in figures 1 & 2. The error bars shown on the plots are approximate 95% confidence intervals based on the standard errors of the estimates. Any lack of independence in the data, which comes from a limited number of individuals who are exposed to broadly similar environmental conditions, will lead these to understate the variability in the estimates.

The mean of the data was 0.31 (95% CI: 0.29-0.33). The mean proportion of the survey windows individuals hauled out for was very variable (Figure 1), though the greatest variability was amongst the animals from which the least data had been obtained. Taking the mean of the estimates for individuals produces a population estimate of 0.33 of the animals being hauled out during the surveys (95% bootstrap confidence interval: 0.29-0.37). Dividing the survey results by these numbers gave an overall population estimate and confidence interval of 81,000 (95% confidence interval: 72,500 – 90,900) (Table 2).

Neither sex ($p>0.3$; Mann-Whitney U-test), nor animal length (Spearman's rank correlation coefficient; $p>0.3$; empirical null distribution) had any significant effect on haulout behaviour. No significant effects of the height above datum of the low tide, neapiness, mean daily temperature, rainfall or wind speed were detected (Spearman's rank correlation coefficient; $p>0.1$, >0.1, >0.8, >0.2, >0.06; empirical null distributions). Similarly, the timing of low tide had no significant effect on the animals' behaviour (Wald-Wolfowitz runs test; $p>0.07$; empirical null distributions).

The permutation test did not identify any statistically significant differences between the regional data (Figure 3). While the 45% of time the individuals in the Inner Hebrides hauled out was above the 95% confidence interval for permuted populations (0.25-0.42), the 16% difference between it and the animals in the Irish Sea lay well inside the appropriate confidence interval (0.04-0.20). Seven out of the 107 tagged individuals moved between regions (Table 1). Some of these also returned to their original regions within the period, further cautioning against considering them separately.

The apparent differences between the years seem to be due to the small sample sizes. Even excluding 1999 and 2001, for which there was very little data, the greatest difference between years (0.10, between the mean values for 2002 and 2003) was non significant ($p>0.9$; permutation test), and is actually less than would be expected from the permutation test (95% confidence interval on maximum difference: 0.12-0.43). Restricting the comparison to the four years containing more than 10 tagged animals, which all have mean haulout proportions in the range 0.32-0.34 produced very similar results ($p>0.9$; 95% confidence interval on maximum interannual difference 0.03-0.21; permutation test).

The only significant pattern detected was temporal. There is a visually striking pattern in the data when mean values are plotted by day (figure 1), which is statically significant against both the shifted and permuted versions (Wald-Wolfowitz runs test; $p<0.01$, $p<01$; empirical null distributions). This was particularly surprising given that the data comes from multiple years and regions. The significance of the weekly patterns is marginal, with the difference between weekend and midweek being insignificant ($p=0.059$, Mann-Whitney U-test, empirical null distribution), but the means for the different days of the week appearing significantly different from each other ($p=0.047$ permutation test). Visually, the pattern seemed to be one of fewer animals hauling out around the weekends (figure 2).

There is some evidence of negative autocorrelation in the individual data. There was insufficient data or variability in the data from 8 tags, and 7 of the remaining 99 tags generated empirical p-values below 0.05, though 4 of these are from tags that produced 5 or fewer datapoints. However, 23 tags produced test statistics greater than 95% of the relevant null distributions, indicating that these animals switched between hauling out for high and low proportions of the survey window more often than would be expected by chance, an observation that is unsurprising given that grey seals generally forage on trips lasting several days.

Estimates of the proportion of animals hauled out were, unsurprisingly, less variable when they were based on more animals (Figure 3). However the average standard errors showed no indication of correlation between the behaviour of individuals (Figure 3). The difference between the two sets of average standard errors are due to the aggregation at regional rather than haulout level producing groups containing more individuals.

The large, and statistically significant variability in the results between days, made it necessary to stratify the bootstrap resampling. This gave an expected proportion of animals hauled out during a synoptic survey of 0.31 (95% CI: 0.15-0.50). Since the other patterns in the data appeared relatively week, each regional population estimate was constructed from sum of the relevant number of draws from the overall distribution of daily haulout proportion (Table 2). The overall population estimate was then constructed by summing the regional results, and gave a total estimate of 88,300 (95% confidence interval: 75,400 – 105,700) grey seals in 2008.

5. Discussion

This analysis has shown that the probability of a seal being hauled out in August, and thus being counted in an aerial survey, is not substantially affected by its age or sex. This suggests that efforts to sex and age animals observed during aerial surveys will have little effect on the resulting population estimates. It , therefore, neatly sidesteps the question of how accurately sex and a proxy of age can be determined from aerial photographs.

It also shows little evidence for geographical and environmental effects on the probability of animals hauling out. It appears that, while individuals differ, there are no obvious consistent patterns associated with any of the potentially explanatory variables we considered. This, and the fact the data came from animals in many areas and many years, makes the substantial differences between different days particularly hard to explain. There seems to be little direct correlation between these animals' behaviour, but on some days of the month the animals' seem to haul out twice as much as on others. Only part of this seems explicable by the autocorrelation in individuals' behaviour. This would seem to suggest that either the animals are responding to a cue we haven't identified, or their movements are directly correlated

Non-parametric bootstrapping and permutation tests make few assumptions about the patterns underlying data. They are generally less powerful than equivalent parametric methods, but, in cases like this, where the patterns of interdependence between datapoints are complex, they provide a robust methodology. They do, however, require the identification of appropriate units for data manipulation and analysis. The large decrease in the estimated precision that results from respecting the variability between different days provides a clear demonstration of the importance of checking the appropriateness of any data aggregation.

This analysis shows the power available from combining the data from large numbers of relatively small telemetry deployments. The biological implication of the remarkable consistency of these results and the daily fluctuations, and their extension to the rest of the year are beyond the scope of this investigation. Hopefully they will be further examined *in due course.*

6. References

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Tables

<table>
<tr><td rowspan="3">year</td><td colspan="13">Region</td><td colspan="3" rowspan="3">total</td></tr>
<tr><td colspan="3">North Sea</td><td colspan="2">Inner Hebrides</td><td colspan="2">Outer Hebrides</td><td colspan="3">Orkney</td><td colspan="3">Irish Sea</td></tr>
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*a pair of asterisks on a row indicates that a single tagged animal was recorded in two regions during august.

Table 1. The number of tagged seals contributing data to this analysis, grouped by year region and sex. Seven of these grey seals (indicated by asterisks) moved between regions during the study periods. Data on the sex of five animals has been mislaid.

egion	Survey			Population estimate (& 95% CI)	
	year	days	count	Simple bootstrap	Day of year bootstrap
North Sea	2008	3	9,407	28,500 (25,500 – 32,000)	31,300 (22,900 – 44,000)
Inner Hebrides	2007, 2009	4	2,852	8,650 (7,740 – 9,700)	9,390 (7,100 – 12,750)
Outer Hebrides	2008	5	3,697	11,200 (10,000 – 12,600)	12,100 (9,500 – 15,700)
Orkney	2008	4	9,388	28,500 (25,500 – 32,000)	31,000 (23,500 – 41,800)
Shetland	2009	5	1,355	4,110 (3,680 – 4,610)	4,440 (3,460 – 5,780)
total	2007-2009	21	26,699	81,000 (72,500 – 90,900)	88,300 (75,400 – 105,700)

Table 2. The number numbers of grey seals counted during the summer surveys, the approximate number of days they were spread over, and the population estimates resulting from scaling the counts by the proportion of tagged animals hauled out. The first column of population estimates comes from a simple bootstrap of the proportion of time each animal hauled out for, using the mean over the datapoints increases all the values by approximately 10%. The righthand column combines estimates of the distribution of haulout proportions on each day of the year, and repeatedly draws the relevant number of days from this combined distribution to represent the uncertainty in the scaling. The difference in the precisions comes from the simple bootstrap sampling hiding the large differences in the proportion of animals hauling out each day.

Figures

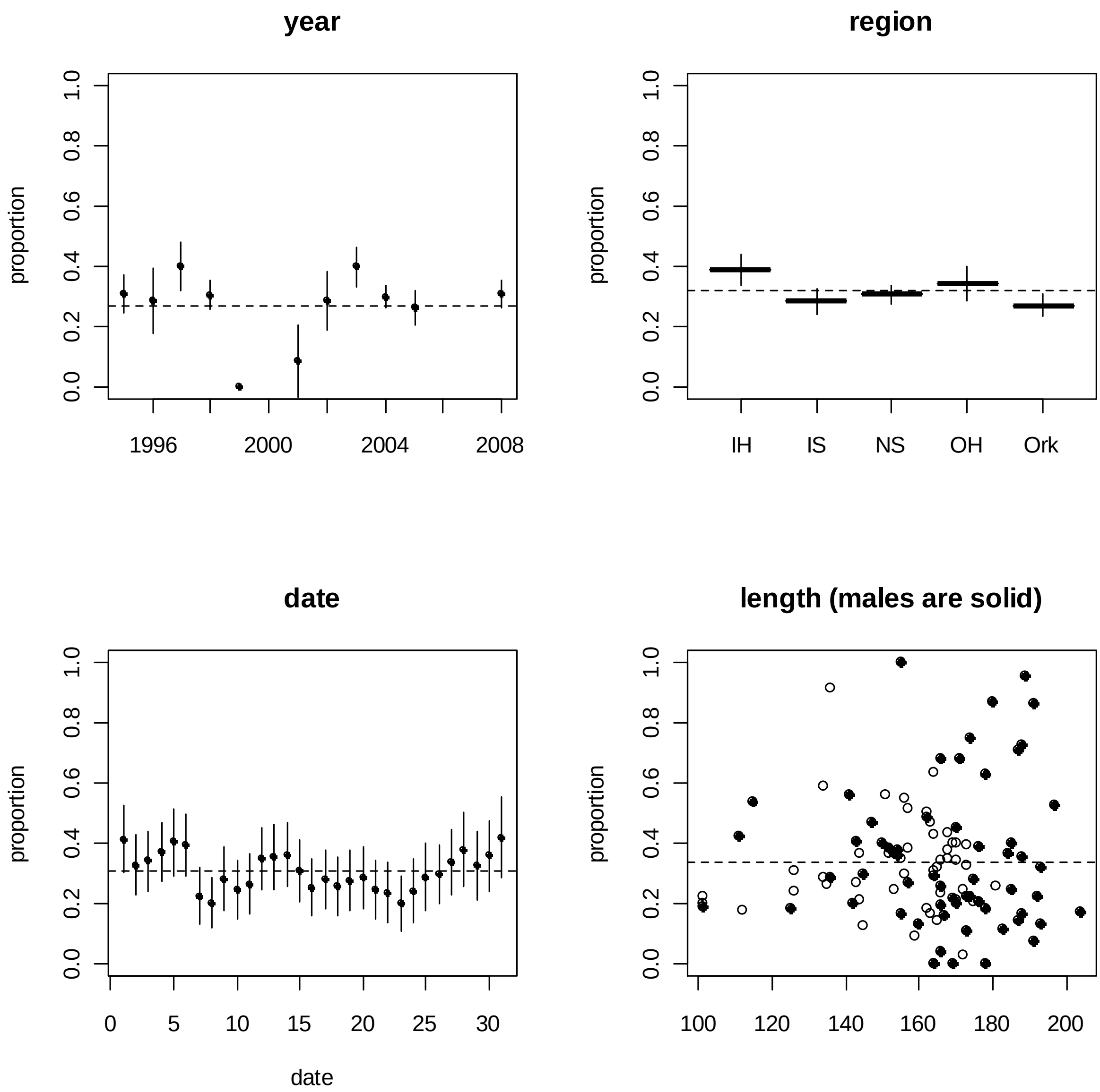

Figure 1. Proportions of the survey windows (2 hrs each side of daytime low tide in August) that the animals were hauled out. Means and standard errors (assuming normality and independence, so probably underestimated) for individual daily data grouped by year, region and day in august,. The lower right plot shows individuals for whom lengths were recorded. Solid circles are males, hollow one females. The broken line in each pane is the mean of that set of points.

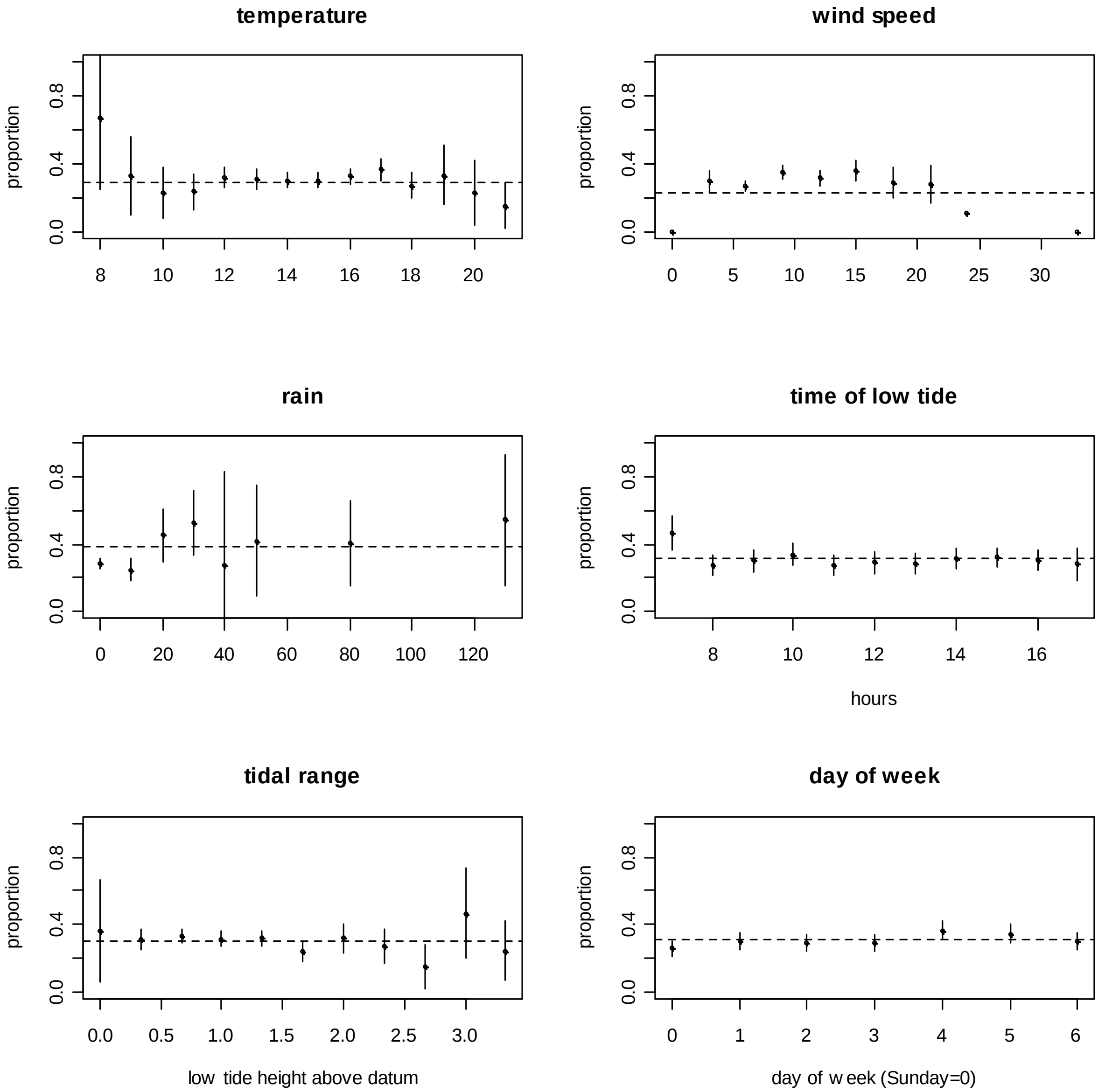

Figure 2. Proportion of the survey window (2 hrs each side of daytime low tide in August) that the animals were hauled out. Means and standard errors (assuming normality and independence, so probably underestimated) for individual daily data grouped by temperature, wind speed, rain, time of day of low tide; the size of the tide; and day of the week. The broken line in each pane is the mean of that set of points.

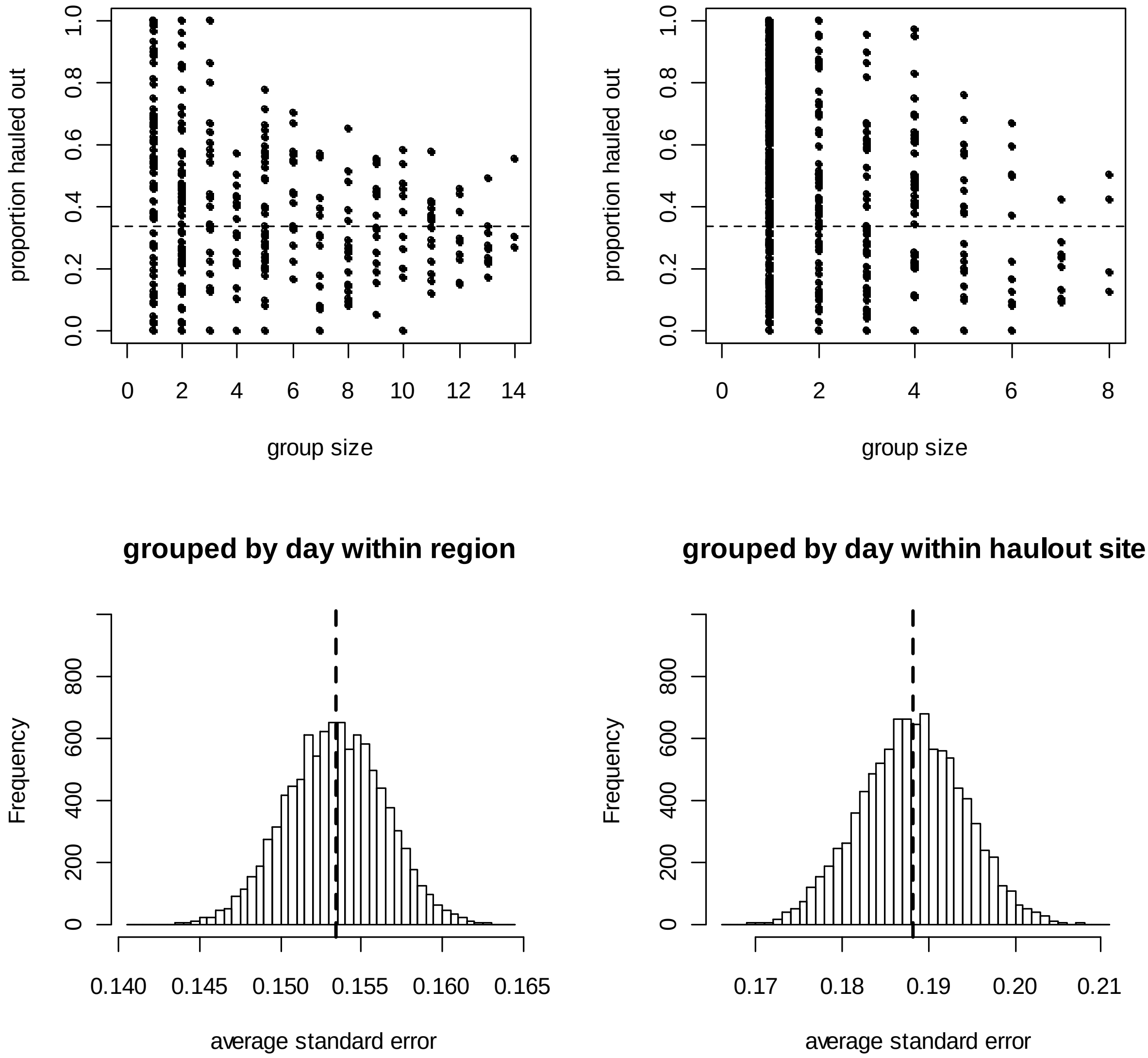

Figure 3. The variability in the proportions of animals hauled out. Each datapoint in the upper left pane is the mean haulout proportion, over the survey window, for animals in one region on one day. The upper right is the equivalent but grouped by local haulout rather than region. The lower plots compare the average standard error of the groups (broken lines) to the distribution of values resulting from permuting the values. Correlation in the animals' behaviour could be expected to produce a line lying to the left of distribution.

D. Thompson[1], S. Bexton[2], A. Brownlow[3], D. Wood[4], A Patterson[5], K. Pye[6], M. Lonergan[1] & R. Milne[1]

Report on recent seal mortalities in UK waters caused by extensive lacerations: October 2010.

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1. Summary

This report describes the occurrence of dead seals with characteristic spiral injuries reported from sites on the UK east coast and in Northern Ireland up to September 2010.

Severely damaged seal carcasses have been found on beaches in eastern Scotland (St Andrews Bay, Tay and Eden Estuaries and Firth of Forth), along the North Norfolk coast in England (centred on the Blakeney Point nature reserve), and within and around Strangford Lough in Northern Ireland (Figure 1). 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 actual observations and, based on the evidence to date, seem very unlikely to have been the cause of these mortalities.

Figure 1. Harbour seal juvenile showing typical spiral wound. Collected in the Eden estuary in St Andrews Bay, July 2009.

2. Occurrence

5 To date (October 2010), examples of these characteristic spiral cuts have been confirmed on seal carcasses from south east Scotland, south east England and Northern Ireland (Figure 2). Details of species, timing and location of strandings are given in Tables 1 & 2.

- In south east Scotland, two adult female harbour seals (*Phoca vitulina*) were found in summer 2008 in St Andrews Bay. Two juvenile and two adult female harbour seals were found in summer 2009 and six adult female harbour seals (5 of which were in late pregnancy) and one adult female grey seal (*Halichoerus grypus*) were found in St Andrews Bay in June & July 2010 (Figure 3). A juvenile grey seal with similar wounds was also found in the Firth of Forth in December 2009.

- Eleven grey seals were discovered on the north Norfolk coast in the vicinity of Blakeney Point between October 2009 and March 2010. A total of 21 female harbour seals and 5 unidentified seals (thought most likely to have been harbour seals based on their description), were found in the same area between April and September 2010 (Figure 4). Two unidentified seals with similar injuries had also been reported at Blakeney in March 2009.

- Several seal carcasses examined in and around Strangford Lough since 2008 have had similar wounds, with the most recent example in the UK being a harbour seal collected from Strangford Lough on 25th September 2010.

There are also various older reports, of carcasses with wounds to the head and thorax, from these and other areas around the UK. Such animals have often been assumed to have died in fishing nets and sustained lacerations when being cut out of nets. However some of these wounds may be consistent with a rotating blade strike and warrant further investigation in light of our more recent observations.

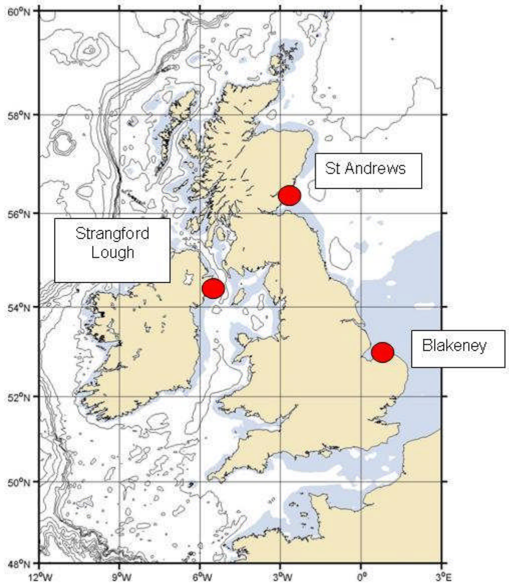

Figure 2. Areas where seals with spiral laceration have been identified so far

Table 1. Spiral cut seals found in south east Scotland, mainly in St Andrews Bay and around the Fife coast between June 2008 and August 2010.

Species	No.	Age & Sex	Date	Location	Comments
harbour seal	1	adult female	05. 06. 08	West Sands	fresh
harbour seal	1	adult female	16. 06. 08	West Sands	fresh
harbour seal	1	adult female	01. 07. 09	Tentsmuir	fresh
harbour seal	1	adult female	06. 07. 09	Tentsmuir	fresh
harbour seal	1	juvenile female	30. 07. 09	Eden estuary	fresh
harbour seal	1	juvenile male	30. 07. 09	Eden estuary	fresh
grey seal	1	juvenile male	06. 12. 09	Inchkeith	fresh
harbour seal	1	adult female	07. 06. 10	Eden estuary	fresh
grey seal	1	adult female	10. 06. 10	Fife Ness	old carcass
harbour seal	1	adult female	15. 06. 10	Eden estuary	fresh
harbour seal	1	adult female	16. 06. 10	Eden estuary	fresh
harbour seal	1	adult female	22. 06. 10	Eden estuary	fresh
harbour seal	1	adult female	25. 06. 10	Monifieth	old carcass
harbour seal	1	adult female	28. 07. 10	Eden estuary	old carcass
harbour seal	1	adult female	26. 08. 10	Eden estuary	

Table 2. Spiral cut seals found on the north Norfolk coast between March 2009 and August 2010. (Unidentified indicates that the carcass was of a seal the species was not determined.)

Species)	No.	Age & Sex	Date	Location	Comments
unidentified.	2	?	23.03.09	Blakeney Point	spiral cut marks
grey seal	8+	?	winter 09/10	Blakeney Point	various ages. spiral cuts
grey seal	3+	?	March 2010	Blakeney Point	old carcasses, spiral cuts
harbour seal	7	adult female	April-June 2010	Blakeney Point	spiral cut marks
unidentified	2	?	May-June 2010	Salthouse/Cley	spiral cut marks
harbour seal	1	adult female	10.06.10	Blakeney Point	spiral cut marks,
harbour seal	1	adult female	30.06.10	Blakeney Point	spiral cut marks
harbour seal	1	adult female	12.07.10	Blakeney Point	spiral cut marks
harbour seal	1	adult female	13.07.10	Blakeney Point	spiral cut marks
harbour seal	1	adult female	14.07.10	Stiffkey- Blakeney	old carcass, cut marks
harbour seal	1	adult female	15.07.10	Blakeney Point	spiral cut marks
harbour seal	1	adult female	16.07.10	Blakeney Point	spiral cut marks
harbour seal	1	adult female	20.07.10	Blakeney Point	spiral cut marks
harbour seal	1	adult female	21.07.10	Blakeney Point	spiral cut marks
unidentified	1	?	21.07.10	Stiffkey-Blakeney	old carcass, spiral cuts
unidentified	1	?	22.07.10	Blakeney Point	old carcass, spiral cuts
harbour seal	1	adult female	23.07.10	Blakeney Point	spiral cut marks
harbour seal	1	adult female	25.07.10	Blakeney Point	fresh, spiral marks
unid. seal sp	1	adult female	26.07.10	Blakeney Point	half a seal cut marks
harbour seal	1	adult female	27.07.10	Blakeney Point	fresh, spiral marks
harbour seal	1	adult female	27.07.10	Blakeney harbour	fresh spiral cuts
harbour seal	1	adult female	28.07.10	Blakeney Point	fresh, spiral marks
harbour seal	1	adult female	03.08.10	Blakeney Point	fresh, spiral marks
harbour seal	1	adult female	03.08.10	Blakeney Point	old carcass, spiral cuts

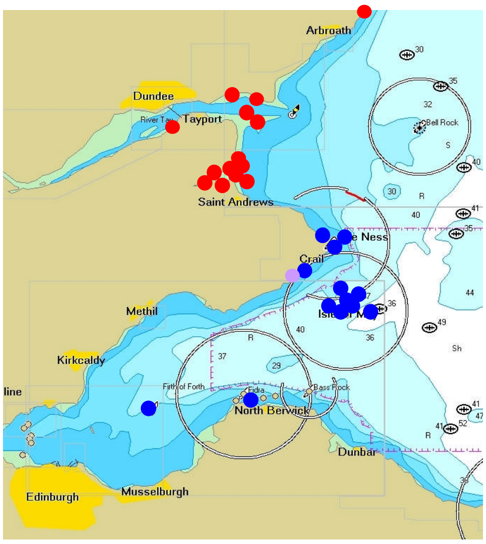

Figure 3. Distribution of spiral cut seal carcasses in south-east Scotland in 2010 & 2011 (RED=harbour seal, BLUE=grey seal). In summer 2008 and 2009 carcasses were restricted to the Eden estuary and West Sands in St Andrews Bay

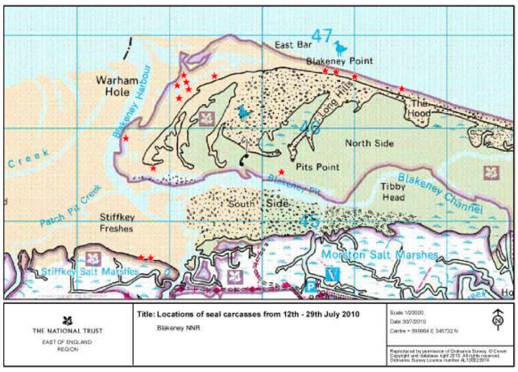

Figure 4. Distribution of seal carcass (marked by a red star) strandings in and around Blakeney in north Norfolk between 12th & 29th July 2010.

3. Pathology

A total 12 harbour seal carcasses from north Norfolk have been necropsied 11 at RSPCA East Winch Wildlife Centre and one at the Veterinary Laboratories Agency. Five harbour seals from St Andrews Bay have been necropsied by the Scottish Agricultural College (SAC). The estimated time between death and when carcasses were necropsied varied between individuals with several estimated to have been dead for only one to two days. Estimates of the time since death (TSD) are notoriously unreliable if carcasses are already showing advanced autolytic change, especially since some bodies may have spent undeterminable periods of time in and out of water. Some carcasses were definitely over 2 weeks old.

In Norfolk all necropsied harbour seals were female, 9 adults and 2 immature animals. Radiographs and close inspection ruled out shooting or other trauma to the head as the cause of death. The key pathological findings were consistent in all seals suggesting a common cause. All had a single continuous wound which started on the left lower jaw and then followed a spiral around the body. The wound ended at different points in different individuals, varying between the bottom of the ribcage and the pelvis. In all cases, the wound followed a clockwise spiral when viewed head-on.

The skin was cleanly cut in a smooth continuous arc in each case (Figure 5) and the blubber and connective tissue had been ripped away (caudally) from the body consistent with a powerful shearing force and with the animal being drawn head-first past the blade causing the laceration. There were no significant bone fractures but the muscular attachments of the scapulae had been torn free in all cases. The cut through the tissue slanted at approximately 35^{o} towards the tail, suggesting the animal was moving forward relative to the cutting device. There was no evidence of cut hair on any of the wounds. This indicates that the cutting edge was not a sharpened blade such as knife or razor and suggests that a smooth edge must have been applied with significant force.

Smaller irregular puncture wounds were present on the muzzles of all the seals in Norfolk. In several cases these wounds appeared to be impressions of a regular serrated edge similar to the shearing blade of a propeller rope cutter attachment (Figure 6).

Figure 5. Photograph of the wound on a juvenile harbour seal. The smooth edged cut through the skin and tearing of the blubber by a lateral shearing force was common to all carcasses examined.

Five harbour seals from St Andrews Bay were necropsied by the Scottish Marine Mammal Strandings programme, two juveniles in 2009 and three pregnant adult females in June 2010. Pathological findings were consistent with those of the Norfolk seals. All cases exhibited corkscrew-shaped wounds, originating on the left hand side of the mouth and spiraling in a clockwise direction as a single, clean-cut continuous spiral around the head and neck, ending in the lumbar region. Unlike the Norfolk seals, few other cut marks were noted on the St Andrews Bay carcasses, but in the two yearling seals the wound cut through the top of the skull.

Figure 6. Facial wound on female harbour seal showing triangular shaped cuts consistent with contact with a propeller rope cutting device.

No grey seal carcasses have been necropsied to date. However, examination of photographs suggests that the pathology is similar, with a single smooth edged cut spiraling around the body. In those cases where the head can be seen on the photographs the wound appears to start further back on the head, at the back of the jaw or on the neck (Figure 7).

Figure 7. Spiral cut wounds on juvenile grey seals from Norfolk (top) and the Firth of Forth (bottom) in both cases the wound starts at the back of the head

There was no evidence of any underlying disorder such as impaired vision or other disease process in any of the seals examined in Norfolk or St Andrews Bay. Blubber thickness was assessed in an unaffected part of the body and was normal for the time of year in all cases suggesting that these were otherwise healthy animals that had been feeding normally. Where present, the stomach contents also indicated recent successful feeding. Two out of 3 seals tested positive for Domoic acid exposure in the St Andrews animals but none of the 10 Norfolk animals tested showed signs of exposure. Domoic acid is an algal biotoxin known to have produced neuropathological symptoms in seals.

Blood loss from such severe injuries would be massive and unconsciousness and death would be very rapid. The impacts on the two juvenile harbour seals found in St Andrews Bay in 2009 caused instantaneous, massive head trauma that would have been immediately fatal. All the seals would therefore have died instantaneously and drifted to shore where they were stranded by the tide. It is uncertain how far they may have drifted but models of currents in the vicinity suggest they died close to shore.

4. Is this a continuing problem?

No new carcasses have been seen in either eastern Scotland or Norfolk since late August. However there does seem to be a seasonal pattern in the findings, particularly around St Andews. On the 25th

September 2010 a grey seal juvenile with the same wound type was also discovered in Strangford Lough in Northern Ireland.

5. Locations where animals died

In both St Andrews Bay and Norfolk a number of the carcasses were from animals that had died very recently when examined and were estimated to have been in the water for around one or two days. Others may have been floating for longer or may have been ashore for some time before being found.
An analysis of the tidal and wave induced surface current in north Norfolk was carried out by K.Pye Associates. For two seals the times of stranding were known to within a few hours. Reasonably accurate TSD estimation was possible for two of the freshly dead Norfolk seals based on a number of factors including gross and histological evidence of autolysis in various tissues. A detailed analysis of the effects of tidal and wave-induced surface currents on these seal bodies allowed a prediction to be made of the likely area in which they died. Results suggest that these two particular seals died within 5 km of the shore, somewhere between Scolt (20km west of Blakeney Point) and Weybourne (12km east of Blakeney Point) with the area between Holkham/Wells and Blakeney the most likely. Furthermore, as the Norfolk seal bodies have all washed ashore along a relatively small stretch of coast, it is reasonable to assume they may have died in the same general area in close proximity to the shore.

A detailed description of the analysis and examples of the estimated drift tracks for both seals can be found in the full report (contact K. Pye@kpal.co.uk). The report also details a longer term analysis for the middle of July when several animals stranded. This analysis also suggested that that the other seals found in Norfolk probably also died within this general area and also suggests that they are likely to have been killed relatively close to shore.

A similar analysis of the potential source for the St Andrews Bay seals is underway. A preliminary investigation based on a simple tidal flow model without wave and wind driven surface currents suggests that again the mortalities are occurring relatively close inshore. The stranding of two juvenile harbour seals in the Eden estuary at the same time and within a few metres of each other is a stong indication that they were killed relatively close to shore.

6. Geographical extent

So far in the UK, confirmed spiral cut seals have been seen in south east Scotland, north Norfolk and Strangford Lough. There are also reports of similar injuries to seals at sites on the Scottish west coast and on the North east English coast but the absence of photographs or poor quality of photographs means that these cannot be confirmed.

Seals with similar characteristic spiral or corkscrew injuries have been reported from Atlantic Canada for at least the last 15 years. For example, both grey and harbour seals with these types of injuries have washed ashore on Sable Island in Canada. Similar injuries were also seen on large numbers of juvenile harp seals in a single mass stranding along the shore of Prince Edward Island in the Gulf of St Lawrence in 1997. In addition, groups of grey seals with similar injuries stranded in Nova Scotia in 2009 and 2010.

Figure 9. Adult female harbour seal carcass stranded at Monifieth in the mouth of the estuary of the river Tay. Despite appearances, the carcass was relatively fresh and when repositioned, the skin and blubber showed the characteristic spiral cut.

It seems likely that the known geographical extent of this problem will increase as more researchers examine their photographic archives and identify similarly damaged carcasses. It is also likely that in the past, such carcasses have been seen but not identified. Figure 9 shows an example of the stranded carcase of a female harbour seals that suffered these injuries. The pattern of injuries was not obvious on initial inspection and could only be identified after the skin and blubber sections had been re-positioned.

7. Mechanism of Injury: Ducted Propellers

We believe that the most likely cause of death for the seals from the UK is associated with the seals being drawn through a ducted (or cowled) propeller, such as a fixed Kort or Rice nozzle or a ducted azimuth thruster.

The principal reasons for this conclusion are:

- The presence of a single, continuous, smooth edged cut appears to be the result of contact with a single blade. The absence of cut hair suggests that the blade was only sharp enough to cut the skin when applied with sufficient force but not razor sharp.

- To produce the spiral cut the seal must have rotated relative to the blade. Although a seal in contact with a large open propeller may rotate it will also be thrown out laterally away from the centre. The multiple rotations of the spiral cut suggest that the carcasses were prevented from being thrown out. This is consistent with the propeller being in some form of duct or cowling. In such a situation the carcass would be expected to roll around the inside of the cowling while being drawn past the blade by the movement of water through the duct.

- Simple trials using model seals with a solid core and a soft plasticine blubber layer showed that ducted propellers can produce such spiral wounds and that a propeller within a duct of approximately 1.6m diameter or larger would be needed to accommodate an adult female harbour seal

- The spacing and number rotations of the cuts on the seals is consistent with the architecture of some ship drive systems. An adult harbour seal or juvenile grey seal can be approximated as a 0.4 m diameter by 1.6 m long cylinder. Drawing this through a cowling containing a 1.8m diameter propeller (i.e. approximately the size of propeller likely to be fitted on a 1000kw thruster) with a pitch of 1.0 to 1.7 times the diameter would produce a cut that spiralled round the cylinder between 2.2 and 3.7 times along the length of the object. The successive cuts would be approximately 0.4 to 0.7 m apart (Pearce *pers com*). The force of water pushing the seal between the angled blades would be large, irresistible, and easily capable of forcing the skin/blubber layer off the underlying muscle and skeleton. The angle of the cuts is consistent with this architecture..

- The presence of patterns, matching the rope cutters that are present on these types of propeller systems, on the side of the head of several animals is also indicative of them being drawn through propellers.

- Ducted propellers and azimuth thrusters are used for the dynamic positioning of vessels. These boats maintain their position by altering the speed and direction of their thrust. This can involve an almost stationary vessel repeatedly starting or reversing its rapidly rotating propellers, a situation that used to be relatively rare. This may increase the opportunities for animals to approach propellers and be drawn into them.

8. Alternative explanations of the injuries

A large number of alternative mechanisms have been suggested by other research groups and the general public. All of these have been considered at length. In response to the wide public and press interest in some of these alternatives we have presented them along with a brief explanation as to why we do not think they are the causal mechanism in this situation.

8.1. Deliberate killing

- The cuts would have been very difficult to inflict manually. Necropsy results indicate that the seals were killed by the cuts, but it would be extraordinarily difficult to produce the single smooth edge cut by hand even on a dead seal and completely impossible on a conscious live animal. The force required to cut the skin with a blade that was not sufficiently sharp to also cut the hair would be well beyond the force that could be applied by a person or even a group of people working together. The consistent nature of the injuries also suggests that those carrying out the cutting would need to have been highly practiced.

- One recurring suggestion has been the existence of purpose built traps/underwater snares. Noting that such traps have not been found and are not known to exist, the mechanism of injury requires that any such device would need to be large, robust and contain a mechanically driven blade of some sort. It is hard to see how such a device could be built, deployed and operated in St Andrews Bay without being observed or detected. There is no evidence for such a device ever having been constructed or deployed anywhere. The simultaneous and secret deployment of similar devices in eastern Scotland, eastern England, Northern Ireland and Sable Island in Canada seems extremely unlikely.

8.2. Fishing activity

- Fish lift/pump systems are used on large pelagic trawlers and seine net boats. These are known to have killed seals in the past by sucking them up into the pump mechanism. Extensive discussion with fisheries technologists, local fishery officers and coast guards confirmed that there were no large scale fishing operations in the inshore areas within 10 to 15 km of either Blakeney or St Andrews Bay.

- Long line fishing was highlighted as a potential source of spiral cuts. In order to cause such an injury, a line would need to wrap around the seal and then be pulled tight enough to cut through the skin. The suggested mechanism involved the seal taking the bait or a caught fish and itself becoming caught on the hook.
  - The consistency of the wound is unlikely to result from such a random event.
  - There were no apparent points where the blade cut deeper. A spiral line drawn tight might be expected to "bite" at certain points and produce cuts of different depth. Hooks are designed to grip rather than cut, and so would seem unlikely to produce clean cuts.
  - There are no longline fisheries near St Andrews Bay and we know of no long line fisheries near Blakeney.
  - There was no evidence of fishing line in any of the wounds

- Dredging for shellfish
  - Shell fish dredging is practiced in Norfolk, occasionally off St Andrews and around Sable Island. However, the gear employed does not contain any mechanism capable of producing the consistent spiral cut wounds

- Fishermen cutting seals from nets.
  - This is not feasible given the consistency and the smooth continuous nature of the wound.
  - Repeated references to fishermen removing seals heads and/or slicing them around the body to get them out of nets do not make sense. Such cuts would not help remove nets and would be extremely messy in terms of blood and oil discharge.
  - The absence of any large scale fishing operations in the fishery exclusion zone around St Andrews Bay and close to Blakeney means that there is no supporting evidence from the localities in which most of the dead seal have been found.

8.3. Self-inflicted injury during escape attempts

- Suggestions that seals are spinning in attempts to escape and cutting themselves on a blade are not feasible given the consistency and severity of the injuries. For example the two juvenile harbour seals in St Andrews Bay in 2009 suffered instantaneous, massive head trauma that was immediately fatal. All carcasses show that the body was dragged past a blade with sufficient force to remove the blubber and skin from underlying tissue. It would be impossible for a seal to maintain the swimming actions needed to inflict such an injury on itself.

8.4 Water Extraction and Dredging

- There are no known fixed mechanical devices with rotating parts large enough to cause these injuries in either area, and no dredging activity other than simple bucket dredging in the Tay and Wells harbours. Bucket dredges do not involve the use of any rotating devices other than the ship propellers on the dredgers themselves.

8.5 Predators

8.5.1 Killer whales

- Killer whales do not possess cutting teeth capable of inflicting cuts like those observed.
- Tearing seals apart would not produce the consistent spiral wounds observed in all seals
- Although occasionally seen off the Fife coast, killer whales do not occur frequently enough in either St Andrews Bay or off north Norfolk to be responsible for even a small fraction of the seals found.

8.5.2. Greenland sharks

- There has been extensive speculation in the media that the spiral cuts are the result of predation by Greenland sharks. This stems from reports from Sable Island where the similar laceration injuries occur and researchers have suggested that they are inflicted by Greenland sharks. There does not appear to be any direct evidence from Sable Island that Greenland sharks are the principle cause of spiral lacerations to seals. We are confident that shark predation is not the cause of these wounds in the UK and sceptical of the connection to Greenland sharks in the Canadian case.

- The wounds observed in the UK are inconsistent with shark predation. It is a single smooth edged continuous cut. Although a smooth edged cut can be produced by the small cutting teeth in the lower jaw of a Greenland shark there is no indication that they are capable of producing a continuous spiral cut. There is no evidence at all that Greenland shark bites produce such wounds on carcasses of seals and no plausible mechanism for them to inflict such wounds. An alternative suggestion that Greenland sharks tear the skin by biting the faces of seals and then thrashing or spinning around is inconsistent with the wounds on UK seals (it requires that the razor sharp slicing teeth leave no marks during the violent thrashing) and implausible (the wounds are identical and clearly caused by a blade cutting in from the outside, in one seal at Blakeney the end of a fore flipper in line with the cut was crushed and cut). We also note that there is no direct observation of Greenland sharks involved in this behaviour. We can find no evidence to support the argument that the spiral tear results from some regular lattice structure in the collagen fibres of the skin and blubber in seals as suggested by some Canadian researchers.

- There are no known observations of Greenland sharks in inshore waters in the UK. They are primarily a cold water species and are thought to move into shallower waters in winter. They are not known from the shallow, relatively warm waters of the southern North Sea in July and August.

- There is no explanation for why any predator would kill large numbers of seals without eating any part of any of the carcasses. Video footage of Greenland sharks clearly shows them removing and swallowing large sections of skin, blubber and muscle from scavenged seal carcasses.

- The shark hypothesis at Sable Island was proposed in part because of a perception that there were few boats in the surrounding area. However this is not consistent with the construction, continued development and operation of an extensive network of gas rigs in the coastal waters off Sable Island, e.g. one rig is only 5km from the island's shore. The development and maintenance of such an industry will have involved a wide range of shipping activity. The presence of these types of vessels appears to be a common feature of the UK and Canadian experiences of spiral cuts to seals.

8.6. Tidal turbines

- Spinning blades on tidal turbines were frequently suggested as likely culprits. They cannot be responsible for any of the seal mortalities on the Scottish or English east coasts because there are no tidal turbines in those regions. The closest operating devices are in the inner channels of the northern Orkney Islands, several hundred miles from the locations at which the, freshly killed, carcasses have been discovered.

8.7. Military activities

- The presence of submarines in the shallow water off Norfolk and within St Andrews Bay is very unlikely. For obvious reasons submarine do not operate normally within shallow waters and the regions concerned are not recognised naval exercise areas.

9. Is this level of mortality important?

The relatively small numbers of seals found would be unlikely to have a significant impact on large seal populations. However, we have no way of estimating what proportion of the casualties we are seeing and it is unlikely that all the mortalities are being recorded.

In St Andrews Bay and the Firth of Tay the harbour seal population has declined dramatically over the past decade. We do not know if the decline is related to this type of mortality but the current level of observed mortality due to this mechanism is unsustainable in this area.

It is not clear which breeding population the Blakeney harbour seals were from. The majority of the English harbour seal population breed in the Wash where pup production is approximately 1200 pups p.a. If we assume a high fecundity rate for this population, the observed mortality would represent approximately 2% of the breeding females. If fecundity is lower, then the observed mortality will represent a lower proportion of the total. Again, it is unlikely that we have seen all the casualties so this must be a minimum estimate of the impact.

We do not know the extent of the problem. We are seeing the carcasses because the seals are encountering the mechanism under a set of conditions that cause them to wash ashore. We do not know if these conditions are necessary for the mortality to occur or just that the particular conditions mean that we are seeing the results of what may be a more widespread but generally unobserved occurrence.
If it is the former, then the problem may be a local phenomenon with limited population scale consequences. However, we know that only a tiny proportion of the 30000+ seals that die each year in UK waters are washed ashore. The probability of observing a seal that dies at sea is therefore low. We cannot rule out the possibility that these stranded carcasses represent fortuitous observations of a more general and widespread process.
The problem may extend to other marine mammal species. Harbour porpoises (*Phocoena phocoena*) exhibiting large lacerations have stranded around the UK and southern North Sea in recent years. In the light of the seal strandings, photographic records of these harbour porpoise strandings are being re-examined.

10. Future Research

There are a large number of potential research questions and it is unlikely that we will be able to access funds to investigate most of them. It is therefore important to prioritise the issues and concentrate on those which are most likely to provide useful information.
Characterising the problem, identifying the mechanism and developing a useful mitigation strategy will require an integrated work programme involving specialists in seal pathology, seal diving and foraging behaviour, marine acoustics and coastal flow processes. They will need to interact with experts in marine technology, shipping and other marine industries. Some of the work has already been started and is reflected in this report.

There are four distinct but interrelated aspects to the investigation. For each of these aspects we present the main questions and suggest a specific work programme to address each:

1. Assessing the scale and extent of the problem

a. Determine the true geographical extent of the problem,

i. all seal carcasses washed ashore in the UK should be examined for signs of these wounds. Where possible wounds should be documented and photographed and where appropriate and practicable the carcasses should be collected and necropsied.

ii. All available information on seal mortality in UK waters should be collated. In the first instance pathology records from the Strangford Lough strandings scheme should be included in the analysis and compared with the records from Norfolk and St Andrews.

iii. an international collaborative effort should be established to identify other examples of the same problem.

b. Characterise the geographical, biological and oceanographic features of the locations where it occurs.

i. An in-depth analysis of wind, wave and tidal current induced movements of carcasses, should be completed for all locations with confirmed corkscrew wounds.

ii. Further analysis of the ship movement patterns around both North Sea sites should be carried out in light of the wave and tidal current modelling work for both sites.

iii. information on the distributions of seal haulouts and foraging patterns, bathymetry and boat/industrial useage characteristics should be compared across sites to identify common features.

c. Assess the intensity of the problem, i.e. assess the number of animals involved

i. Methods for estimating the intensity of the problem will be developed in light of information from a & b above

2. Identifying and then testing the most likely causal mechanisms.

a. Use literature, expert advice and presence/absence to identify candidate mechanisms

i. Continue the current investigations and expand the network of researchers/engineers contributing information and suggestions.

b. Test the candidate mechanism

i. Scale models of seals (using ballistic gel and semi-rigid cores) should be tested in scale models of ducted propellers and other candidate mechanisms of injury.

ii. Full scale carcass tests should be carried out on those mechanisms identified by scale tests

1. intact/suitably freah carcasses of both grey and harbour seals should be collected and stored in a freezer facility.
2. industrial partners/government departments should be encouraged to supply vessel time for testing.

c. Use ship and industry records to identify specific devices where possible.

i. Use AIS ship tracking software and shipping /offshore industry records to determine the locations and operation patterns of vessels with candidate mechanisms.

3. Determining the conditions under which the mechanisms become lethal to seals

It is clear that the seals are responding inappropriately to some aspect of the operation of these devices. The localisation in space and time of these events makes it unlikely that the seals are being hit as a result of random coming together of swimming animals and fast moving vessels. The concentration of carcasses in each locality suggests that the vessels must be either stationary or slow moving but operating their propellers, such as when using motors for dynamic positioning. This suggests that some aspect of the operation of these devices is attracting the seals to within a danger zone from which they do not appear to be able to escape. Developing any mitigation measure will require that we identify and understand the attractive mechanism.

Two possible/likely mechanisms would be attraction to concentrations of food associated with the vessel and an inappropriate response to an acoustic signal from the motor/ship/propeller. An acoustic cue is suggested by the fact that all seals killed during summer month have been female harbour seals which are thought to be attracted by underwater calls of breeding males. Juvenile grey seals which are the main victims during winter months in Norfolk and Scotland have also been shown to be attracted by conspecific calls with a pulsing rhythmic pattern.

a. Characterise the acoustic signatures of the potential causal mechanisms

i. Collaborate with industry to obtain a comprehensive set of recordings of acoustic signals from candidate mechanisms identified above. Use a combination of captive animal studies and tests on wild free ranging seals to identify which if any of these signals are strongly attractive to seals.

ii. Collaborate with fisheries scientists and technologists to determine the likelihood that specific mechanisms or the vessels themselves may act as fish concentration devices.

4. Identifying and testing potential mitigation measures.

It would be premature to suggest the development of specific mitigation measures before the research projects detailed above have identified the causal mechanism and the conditions under which these events become more likely. However, it is essential that appropriate actions are taken as soon as we have sufficient information.

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Harbour seal (*Phoca vitulina*) abundance has declined in Orkney: an assessment based on using ARGOS flipper tags to estimate the proportion of animals ashore during aerial surveys in the moult.

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Abstract

1. The numbers of harbour seals (*Phoca vitulina*) counted during aerial surveys of the Orkney Islands have declined. This work investigated whether these observations could result from behavioural changes rather than a real reduction in abundance.
2. Only animals hauled out on land are visible to the surveys. Data from electronic telemetry tags, containing ARGOS transmitters, were used to scale the counts up to population estimates. The surveys were carried out in August, during the annual moult, so the tags were attached to the animals' flippers instead of being glued to their fur.
3. Data was obtained from 13 animals in Orkney, plus another 9 in western Scotland. In both areas, the proportion of animals hauled out was similar to reports from other, apparently stable, populations.
4. Females hauled out for more of the survey window (0.84; bootstrap 95% confidence interval 0.63-0.99) than males (0.61; bootstrap 95% CI 0.34-0.86).The animals hauled out less during weekends (0.57; bootstrap 95% CI 0.40-0.74) than during the week (0.76; bootstrap 95% CI 0.58-0.91).
5. If the sex–ratio of the population was close to 1-1, the Orkney population of harbour seals was around 3182 (bootstrap 95% CI 2704-4155) animals in 2010. A female-skewed sex-ratio would reduce these population estimates and a changing sex-ratio might mean the counts understate the real decline.
6. The annual rate of decline in the Orkney population of harbour seals was estimated at 13%, (95% CI 10.8-14.8),
7. The population of harbour seals at Arisaig has been increasing at around 2% (95% CI: 1.5-2.4) per year and numbered around 923 animals (95% CI: 765-1169).
8. This study shows that data from a small number of telemetry tags can be used to convert the results of aerial surveys to abundance estimates for pinniped populations.

Introduction

Until recently, the harbour seal (*Phoca vitulina*) population associated with the Orkney Islands, off north-eastern Scotland, was one of the largest in Europe (Thompson, Duck and Lonergan 2010). Declines have been reported in counts of harbour seals throughout eastern Scotland, and the counts from eastern England have not recovered since the 2002 epidemic of phocine distemper (Lonergan *et al.*, 2007). In Orkney the annual rate of decline was estimated at 12% (95% CI: 8-16) over at least a five year period (Lonergan et al., 2007). A set of studies, including this one, were therefore initiated to investigate the state of the population.

Moult surveys, carried out during the first three weeks of August, are used to monitor British harbour seal populations (Thompson Lonergan and Duck, 2005). Surveying is particularly difficult on convoluted and rocky shores where helicopters fitted with thermal imagers are required (Lonergan et al., 2007). Similar moult surveys are carried out for some other harbour seal populations (Small, Pendleton and Pitcher, 2003; Teilmann, Riget and Harkonen, 2010). In other areas, breeding season surveys, which have broadly similar precisions to moult surveys, are used instead (Ries, Hiby and Reijnders, 1998; Brown *et al.*, 2005; Gilbert *et al.*, 2005).

As aerial surveys mainly count hauled out seals, they provide only minimum population estimates. Animals at the surface of the water near haulouts are counted, but those underwater or out at sea are generally missed. The results of aerial surveys can be used as indices of abundance, provided the expected proportion of the population observed remains constant. Studies in other areas, (Huber *et al.*, 2001; Simpkins *et al.*, 2003; Harvey and Goley, 2011) have estimated the proportion of harbour seals available to be counted during the moult at around 0.6-0.8. A similar proportion was also suggested by a previous study of 5 radiotagged female harbour seals in Orkney (Thompson and Harwood, 1990). However, none of these estimates come from a population undergoing a rapid and sustained decline in apparent abundance similar to that reported from Orkney.

Mark-recapture methods provide the most straightforward way to scale observations up to population estimates. Direct approaches, using either natural or artificial markings are only practical for populations that haul out within a restricted area. Radio tracking techniques weaken this requirement somewhat, but still require human involvement, either directly in the collection of the data or simply to service radio receivers at the study site (Ries *et al.*, 1998; Gilbert *et al.*, 2005). Satellite telemetry, where electronic devices automatically collect and transmit behavioural information, removes this constraint and also provides information on behaviour over an extended period, allowing estimates to be made of the precision of results. Electronic tags are usually attached to seals by gluing them to the fur on the back of the animals' heads. This maximises message transmission, minimises the effect of the tags on animals and means that the tag detaches automatically during the moult. This detachment prevents the use of such tags for rescaling the results of surveys carried out during the moult into population estimates.

This study therefore uses electronic transmitters attached to flipper tags to investigate harbour seals' haulout behaviour around low tides during the moult. It has two specific aims: to compare the proportion of animals that could be expected to be hauled out during moult surveys in the declining Orkney population with equivalent values for both the stable population at Arisaig, on the west coast of Scotland, and previously published estimates for other areas; and to use this information to rescale data from aerial surveys into estimates of the abundance of harbour seals.

Materials & Methods

A total of 25 harbour seals were caught in June and early July 2009, seven males and eight females in Orkney and five of each sex at Arisaig, on the west coast of Scotland (Fig. 1). The animals are described in the online supplementary material (Table S1). Each animal had a SPOT5 flipper tag (Wildlife Computers, www.wildlifecomputers.com; mass=40g) attached to a hind flipper. Two screws inserted through 8mm diameter holes pierced in the web between the second and third digits connected a backplate to the tag. Mild steel screws were used so that their corrosion would allow the tags to detach. Plastic collars surrounded the screws where they passed through the flipper and prevented the attachment compressing the web. The tags use the ARGOS satellite system to transmit information including summaries of the proportion of each hour of a day that the tags were dry. Details of the format of this data, and how it was checked for errors and cleaned, are contained in the online Supplementary Material.

Aerial surveys of Scottish harbour seals are carried out during the first three weeks of August. These surveys are generally carried out in the four hours around low tide on days when that occurs between 11:00 and 17:30 (GMT) and the weather is good (Thompson et al., 2005). Seven complete surveys of the Orkney Islands have been carried out with a consistent methodology (Table 1; Fig. 2). Another survey was attempted in 2009, but curtailed by bad weather. There was also one earlier survey, though differences in technique prevent direct comparisons of its results with the others. Six surveys have been carried out at Arisaig (Table 1; Fig. 3).

The telemetry data was aggregated into estimates of the proportion of each survey window that each animal was hauled out for. Tidal data (Poltips version 3.2, Proudman Oceanographic Laboratory) from Mallaig were used for the data from Arisaig, and those for Kirkwall for the Orkney animals. Within Orkney, in particular, the timing of low tides can vary substantially over relatively small areas, so the animals may have experienced tidal patterns up to 1 hour different from those used here. The detail in the available location and tidal data was insufficient to work at any finer resolution.

The data analysis was essentially a bootstrap estimate of the uncertainty in the proportion of animals hauled out, and therefore available to be counted. Surveys are not carried out in poor visibility, high winds or rain, largely because of the practical difficulties, though the suitability of conditions is a matter of judgement rather than formally defined. The effects of visibility, wind and rain on haulout behaviour were therefore checked. Daily rainfall, wind speed, and mean temperatures were obtained from meteorological stations at Kirkwall Airport in Orkney and Lusa on Skye (Fig 1). Seals have been reported to exhibit diurnal patterns (Grigg *et al.*, 2002) and respond to air temperature, so the effects of these were also investigated. Sex differences and changes through August were examined and the autocorrelation in individual animals' behaviour was assessed.

The analysis was carried out, in R (R_Development_Core_Team, 2010), in four stages. First the effects of the various potential explanatory factors were examined. The independence of the behaviour of animals was then assessed to examine the effects of unmeasured covariates and effective sample sizes. Next the distribution of proportions of the population hauled out during the survey window was estimated from bootstrap resamples of the telemetry data. Finally the aerial survey data were divided by values drawn from this distribution to give overall estimates of population sizes and trajectories. The stochastic variation in the numbers of animals counted during surveys was ignored because its variance is much smaller than the other uncertainties in the estimate.

The mean proportions of the time that animals hauled out were calculated for each sex and in each area. Mann-Whitney U-tests were used to examine differences, with the results compared to an empirical null distribution, generated by repeatedly permuting the sex of the animals or their locations, to account for ties and non-independence in the datapoints. Relationships with daily mean data were also plotted out and examined.

Spearman's rank correlation coefficient was used to look at the effects of day of the year, tidal height, the time of day of low tide, temperature, wind speed, rainfall and visibility on haulout behaviour. Because the data are not independent, the significance of the results was evaluated by bootstrapping, with animals as the unit of resampling. The position of zero in the resulting distribution of correlation coefficients was used as a measure of the statistical significance of the results.

Temporal autocorrelation in the data was investigated with the Wald-Wolfowitz non-parametric runs test (Wald and Wolfowitz, 1943), with an empirical null distribution from permuted values. This was done at the individual, regional and overall level. The short series of data available limited the power to detect these effects. The significance of the difference between weekends and weekdays was investigated by bootstrapping the data with animals as the unit of resampling.

An overall estimate of the expected proportion of the population hauled out during the survey window was calculated as the mean of the proportion of the time the individual animals were hauled out. A bootstrap estimate of the variability in the proportion of animals hauled out during survey windows was made from 10000 replicate draws from the data. This process was repeated separately for males and females, and weekends and weekdays. The validity of the resulting confidence intervals depend on the independence of the behaviour of the individual animals. (Montgomery, Hoef and Boveng, 2007)

The probability distribution for the proportion of animals that would be observed during surveys was estimated by repeatedly drawing 22 points from the dataset. A simple bootstrap will underestimate the variability of future samples taken from a structured dataset. The sex-ratio of these populations is unknown, and the results suggested that males and females hauled out for different proportions of the survey windows. Two extreme scenarios were therefore examined: that there are equal numbers of each sex, and that there are so few males in the population that they can be ignored in estimating abundance. These are likely to bracket the true state of the populations, since it is very unusual for mammal populations to contain more males than females. Each of the Orkney surveys was carried out over several days, so the overall distribution of the proportion of animals observable during them was estimated by summing the appropriate numbers of draws from the distributions for weekend and weekdays. For each scenario, each of the survey counts was divided by the relevant distribution of haulout proportions and the results were plotted.

Minimum rates of decline were calculated for Orkney by comparing the 95th percentile of the 2008 population estimates to the numbers of animals counted in 2010. These are conservative because they effectively assume that every animal was hauled out during the 2001 survey, but they put a lower bound on the decline of the Orkney population.

To examine the trends in the aerial survey data, and estimate the uncertainty in and significance of these trends, generalised linear and generalised additive models (Wood, 2006) were fitted to the comparable counts for Orkney. The variability in the counts was expected to be over-dispersed relative to the Poisson distribution, so a quasipoisson error structure was used (Hoef and Boveng, 2007). It was considered implausible that the errors would be underdispersed relative to the Poisson, so the variance of the error distribution was constrained to be no less than its mean. The gam contained a cubic smooth of year, with six knots. This was fitted with the mgcv library, with gamma set to 1.4 to reduce overfitting (Wood, 2006). Visual inspection suggested a breakpoint a bit before 2001 (Fig. 2), so the glm only included data from that point on. The two counts that were not included in the analysis were compared visually to the results of the two models (Fig. 2).

The trends in the Arisaig population were investigated by fitting a glm with a quasipoisson error structure to that data. The results of the 1996 survey were considered an outlier, being less than half the other values.

Results

Data, relevant to this analysis, was received from 22 of the animals, seven males and six females in Orkney and four males and five females in Arisaig. Most animals provided data for the majority of the survey windows (Fig. S1). The ARGOS system estimates tag locations from Doppler effects on the transmissions (ARGOS, 1996). Examination of the 551 good quality (LQ 1-3) location estimates obtained in August showed that the animals remained relatively close to where they were caught (Fig. 1). The majority of tags produced data for most days in August (Supplementary material Fig. S1). Detailed examination of multiple copies of data suggested that around 1 in 500 bits of the data were corrupted (Supplementary material). There were a total of 562 messages, each describing one animal's haulout behaviour for one day in August, that perfectly matched the data format.

The proportion of the survey windows that individual animals hauled out for was very variable (range: 0.37-1). The mean over all the animals was 0.72 (bootstrap 95% confidence interval: 0.54-0.88) (Table 1).

Females hauled out significantly more (0.84; bootstrap 95% CI: 0.63-0.99) during the survey windows than males (0.61; bootstrap 95% CI: 0.34-0.86). But no significant difference was detected ($p>0.4$; Mann-Whitney U-test; empirical null distribution) between Orkney (mean 0.71; bootstrap 95% CI: 0.63-0.78) and Arisaig (mean 0.76; bootstrap 95% CI: 0.70-0.83), with two thirds of the difference between the point estimates being apparently explicable by the difference in the sex-ratios of the two groups of animals tagged. All these values are consistent with those obtained in previous studies (Thompson and Harwood, 1990; Huber *et al.*, 2001; Simpkins *et al.*, 2003; Harvey and Goley, 2011), suggesting that the declining counts are not due to changes in haulout behaviour.

Investigation of other factors was limited by the size of the dataset. No significant trend through time was detected ($p>0.1$; Spearman rank correlation fitted to bootstrap resamples of animals). However, the proportion of time animals were hauled out was significantly lower (0.57, bootstrap 95% confidence interval 0.40-0.74) at the weekend than midweek (0.76, bootstrap 95% confidence interval 0.58-0.91). The difference between weekdays and weekends appeared larger for males than females (Table 2). No significant effects were detected for date, tidal height, the time of day of low tide, temperature, wind speed, rainfall or visibility ($p>0.1$ in each case; Spearman rank correlation with empirical null distributions). The differences and confidence intervals estimated above suggest an approximate upper limit on the potential effect of the environmental factors.

There was no evidence of autocorrelation in the data series either individually or when aggregated (all $p>0.05$; Wald-Wolfowitz runs test; 3 animals had insufficient data to test). Similarly, the means of the variances for the four classes fell within the null ranges ($p>0.1$; permutation test). This lack of correlation supported the use of bootstrapping to estimate the variability of surveys.

The Orkney harbour seal population was estimated at around 3586 animals (95% confidence interval: 2970-4542) in 2010 under the assumption that the sex ratio was even. If most of the population was female, the abundance was estimated at around 3182 animals (95% confidence interval: 2704 - 4155) in the population. In Arisaig the equivalent figures for 2007 were 923 animals (95% confidence interval: 765-1169) or 819 animals (95% confidence interval: 696-1070). Fig. 2, Fig. 3 and Table 1 give population estimates based on previous surveys and the same scaling factors.

The interval estimates for the multiplier from survey count to population estimate were very conservative. For all days together, the range was 1.02-2.6. The upper bound of this came down to 1.7, if females were considered to make up at least half of the population.

Comparison of the 2010 population estimate to the 2001 count shows that, even if every animal was counted in 2001 there would have been a 95% chance of the population having declined by at least 36% between then and 2010. The glms suggested that the Orkney population was declining at an annual rate of 13%, (95% CI 10.8-14.8), assuming the sex-ratio in the population hadn't changed. The gam suggested a very similar pattern, and gave no indication that the decline was slowing (Fig 2). The Arisaig population was increasing at 2% (95% CI 1.5-2.4) (Fig 3). The error distributions in the Orkney models were overdispersed, but the Arisaig one was not. Refitting the Arisaig model to the full dataset, including the 1996 count, produced the same estimate of trend, though it was non-significant ($p>0.2$).

Discussion

The primary aim of this study was to establish whether the declines in the numbers of harbour seals observed in Orkney during the moult surveys could result from changes in the animals' behaviour. That could not be determined from the count data alone, but is demonstrated by the upper limits of the confidence intervals for the 2007, 2008 and 2010 abundance estimates being below the numbers of animals counted during the 1993, 1997 and 2001 surveys. The estimates of changes in abundance, over the last ten years, clearly indicate that the Orkney harbour seal population has declined substantially. Over the same period, the population in Arisaig has gradually increased. As the haulout behaviour in the two areas was indistinguishable, and similar to the results of previous studies in Orkney (Thompson and Harwood, 1990) and other areas (Huber et al., 2001; Simpkins et al., 2003; Harvey and Goley, 2011), changes in this behaviour seem unlikely to explain any of the reductions in the counts. Visual inspection of the trend in the Orkney population, and the gam model of it (Fig. 2; Supplementary Fig. S3), gives no suggestion that the decline is slowing.

The approach taken to the data in the first part of the analysis is similar to that used in Bayesian analyses: the counts are taken as true and an uncertain scaling applied to them. The second part, estimating trends from survey data alone, is more similar to other analyses of trends in the numbers of animals observed hauling out (e.g. (Lonergan et al., 2007; Teilmann et al., 2010). It might be possible to improve the precision of the population estimates by combining the two types of information. Another potential way to increase the precision of the estimates would be to exploit the spreading of each Orkney survey over 2 or 3 days (Table1) and represent the proportion of animals detected by the mean of 2 or 3 draws from the relevant probability distribution. However, that would require a larger dataset to support its additional assumptions about the autocorrelation in animals' haulout behaviour.

The estimation of the range of scaling factors takes an extremely conservative view of the available knowledge about haulout behaviour. Its main value may be as a reminder that even a uniform prior that spans the correct range of parameter values adds information and increases the precision of estimates. For small datasets, this effect may have important consequences.

If surveys had been completed in 2009, the proportions of those survey windows that animals were hauled out for could have been used to directly rescale the aerial survey data. While that would have removed one source of uncertainty, the precision of the abundance estimates would have had to have been separately estimated from bootstraps of the data from animals in each area, increasing the effects of stochasticity. The small sample size is already a major source of uncertainty in the estimates of the proportion of time animals are hauled out during the survey window. Examination of the variability of reduced bootstrap replicates containing 5, 10 or 15 datapoints (Supplementary Fig S2), suggested that sampling error dominated the uncertainty in the telemetry-based estimate of the proportion of animals hauled out during the survey windows. The estimated precision was therefore concluded to be only appropriate to estimating the uncertainty in population estimates, and unsuitable for identifying trends in the count data from the aerial surveys.

Previous attempts to use telemetry to estimate the proportion of animals hauled out during moult surveys (Ries et al., 1998; Huber et al., 2001; Simpkins et al., 2003; Harvey and Goley, 2011) have used VHF radio tags rather than satellite telemetry. Those tags did not archive information, but instead relied on receivers either in dedicated ground stations or on aircraft. The approach presented here reduces the risk of bias from animals hauling out beyond the range of the receivers or the radio waves being blocked or attenuated by animals, rocks or other features.

All modelling involves balancing detail and power against assumptions. The problem is particularly acute for small datasets, such as this one, and the appropriate solution depends on both the dataset and the purpose of the investigation. In this case a relatively simple approach provided an unequivocal result, limiting the need to make additional, uncheckable, assumptions.

The differences identified in the proportions of males and females hauling out during the moult survey windows complicate the interpretation of the survey results. Unfortunately there is no information available on the sex-ratio of this population. Strandings data is sparse and susceptible to multiple biases. The steep ongoing decline of the Orkney population suggests caution in applying data from other, more stable, populations. Such data is, anyway, very limited. However, the similar numbers of both sexes captured during the study, could be considered evidence that a substantial proportion of the population is male. Other data, such as that from sex determination during scat analysis might help to clarify this and reduce the uncertainty in these population estimates.

The clear difference between haulout behaviour at the weekends and on weekdays may be due to disturbance from inshore recreational activities. However, it is not possible to determine its causes from this data. While the effect needs to be taken into account in the design and analysis of future surveys, its implications for the welfare of the animals may be even more important. It, and the size of the reported differences between the sexes, also suggest an approximate upper bound on any undetected effects of the other covariates investigated. The limited amount of data prevented the simultaneous examination of all the environmental parameters, and this set of investigations would have been excessive if the aim was to identify interesting relationships. However that restriction is less relevant in studies such as this where the purpose is to determine whether a simple analysis can adequately represent uncertainty.

All studies involving sampling from populations are open to biases from differences in individuals' catchability. In this case studying behaviour in the moult of animals caught more than a month earlier may provide some protection from these risks, since the factors controlling individuals' behaviour during these two time periods are likely to be very different. A more difficult issue is that small, and therefore young, animals tend to be underrepresented in telemetry studies (Harvey and Goley, 2011). Very young harbour seals are known to start to moult before mature individuals (Thompson and Rothery, 1987; Harkonen, Harding and Lunneryd, 1999). However, several factors limit the potential impact of this on the current survey: individuals take several weeks to complete the moult; moulting is not perfectly coordinated; the surveys were timed to occur in the middle of the moult; and the likelihood that this rapidly declining population will contain relatively few young animals.

The similarity of the proportion of animals hauled out during these surveys to that observed in other populations seems to suggest that this, relatively straightforward, process can be used to scale moult surveys up to pinniped population estimates, and that behavioural changes are not responsible for the observed declines in numbers of harbour seals counted in Orkney.

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Table Legends

Table 1. The dates of moult surveys in Orkney and at Arisaig, and the numbers of harbour seals counted. The population estimates are based on assuming either an equal number of animals of each sex or that the almost all the animals are female. In each case the bootstrapped distributions in Table 2 are used, mixed according to the proportion of weekdays and weekends during which each survey was carried out.

Table 2. Mean and 95% confidence intervals for the proportion of harbour seals hauled out and therefore available to be counted during August moult surveys.

Figure Legends

Figure 1: Map of study locations showing good quality (LQ>0) ARGOS locations obtained from the telemetry tags during August. "K" and "L" indicate the locations of the weather stations (Kirkwall Airport, in Orkney, and Lusa, on Skye) that supplied the metrological data used in the analysis.

Figure 2. Moult survey counts (squares) and population estimates for harbour seals in Orkney. Triangles scale the counts using the assumption that there are as many males as females in the population, circles assume almost all surviving animals are female. The bars are bootstrap 95% confidence intervals. The solid and dashed lines are the mean and 95% confidence intervals for a quasipoisson glm fitted to the counts from 2001 onwards. The dotted lines show a gam fitted to the count data. The hollow squares are not used in the model fitting because they were collected with a different methodology (1989) or they are not independed (2009, partial count scaled up using data from 2008).

Figure 3. Moult survey counts (squares) and population estimates for harbour seals in Arisaig. Triangles scale the counts using the assumption that there are as many males as females in the population, circles assume almost all surviving animals are female. The bars are bootstrap 95% confidence intervals. The solid and dashed lines are the mean and 95% confidence intervals for a poisson glm fitted to the counts. The 1996 survey (hollow square) was not used in the model fitting because it appears to be an outlier.

Table 1

Location	Year	Date (in August)	Weekday(s)	Count	Population estimate (95% CI)	
					Equal sexes	All female
Orkney	1993	5, 6	Th, F	7873	10502 (8700-13304)	9321 (7919 -12169)
	1997	1, 2, 3, 16	F, Sa, Su, Sa	8523	12055 (9894–15361)	10930 (8955 -14574)
	2001	18, 20	Sa, M	7752	11305 (9233-14439)	9738 (8055 -12912)
	2006	5, 6, 7	Sa, Su, M	4256	6020 (4941-7671)	5458 (4472 - 7277)
	2007	10, 11, 13	F, Sa, M	3379	5073 (4120-6505)	4150 (3465 - 5473)
	2008	14, 15, 16	Th, F, Sa	2867	4315 (3504-5532)	3530 (2947 - 4655)
	2010	10, 11, 12	Tu, W, Th	2688	3586 (2970-4542)	3182 (2704-4155)
Arisaig	1988	8	M	456	608 (504-771)	540 (459-705)
	1989	7	M	499	666 (551-843)	591 (502-771)
	1996	5	M	213	284 (235-360)	252 (214-329)
	2000	18	F	597	796 (660-1009)	707 (601-923)
	2005	10	W	650	867 (718-1098)	770 (654-1005)
	2007	21	Tu	692	923 (765-1169)	819 (696-1070)

Table 2

	males	females	together
weekday	0.66 (0.39-0.90)	0.86 (0.65-0.99)	0.76 (0.58-0.91)
weekend	0.41 (0.18-0.64)	0.76 (0.55-0.93)	0.57 (0.40-0.74)
together	0.61 (0.34-0.86)	0.84 (0.63-0.99)	0.72 (0.54-0.88)

Figure 1

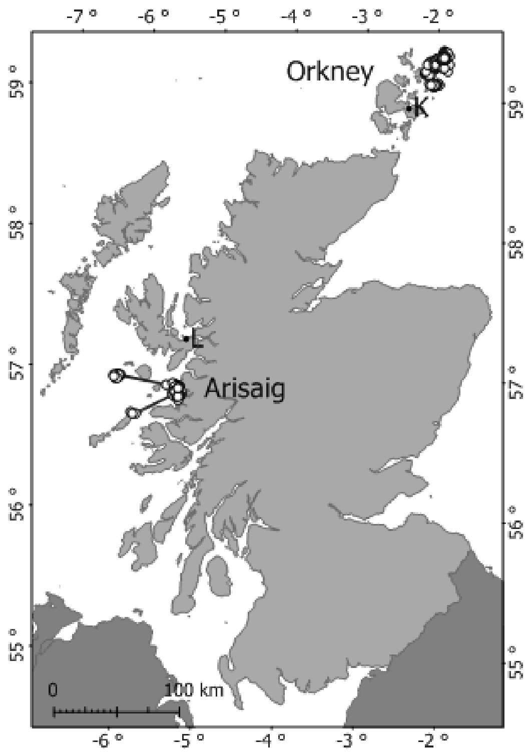


Figure 3

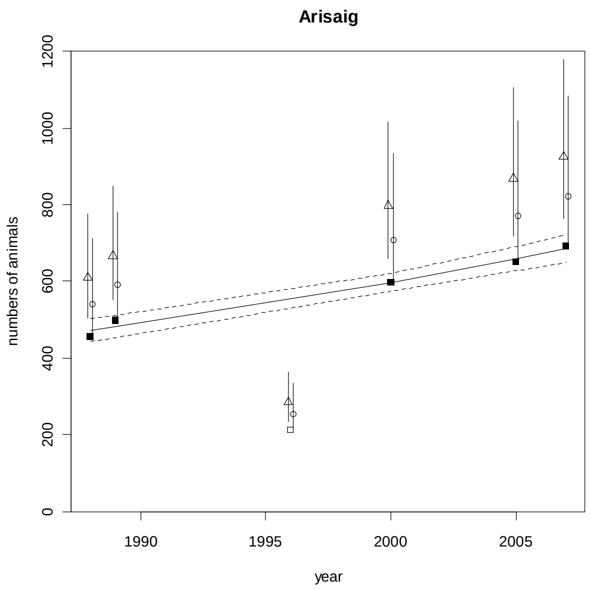
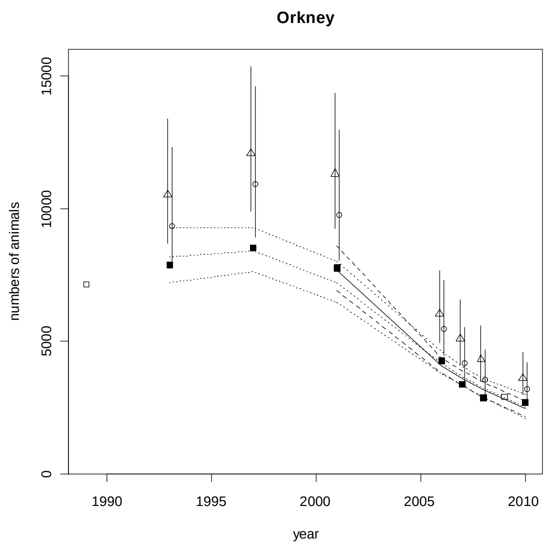


Figure 2



Supplementary material

Sizes of animals

Location	sex	Date tagged	Length (cm)	Girth (cm)
Orkney	f	10/06/2009	142	117
Orkney	f	10/06/2009	144	100
Orkney	f	10/06/2009	144	108.5
Orkney	f	10/06/2009	138	107.5
Orkney	f	10/06/2009	136	98
Orkney	f	10/06/2009	144	115
Orkney	m	11/06/2009	159	118.5
Orkney	f	11/06/2009	145	124
Orkney	f	11/06/2009	142	109
Orkney	m	10/07/2009	155	108
Orkney	m	11/07/2009	151	114
Orkney	m	11/07/2009	152	115
Orkney	m	11/07/2009	149	110
Orkney	m	11/07/2009	144	111
Orkney	m	12/07/2009	150	118
Arisaig	m	16/07/2009	159	104
Arisaig	f	17/07/2009	140	93
Arisaig	m	17/07/2009	148	107
Arisaig	f	17/07/2009	141	94
Arisaig	f	18/07/2009	135	98
Arisaig	m	18/07/2009	136	109.5
Arisaig	f	18/07/2009	128	103
Arisaig	f	18/07/2009	146	83
Arisaig	m	18/07/2009	143	106.5
Arisaig	m	18/07/2009	149	111
Orkney	m	11/06/2009	144	109

Table S1: Length, girth and sex of animals.

Telemetry data preparation

As well as information on hauling out, SPOT tags send additional messages containing information on the total numbers of messages they had sent and the condition of their batteries. Some of these tags were also programmed to report temperatures, though that data is not analysed here.

The tags contain a conductivity sensor that indicates whether they are wet or dry. They summarise this data into 128 bit messages, which are padded with eight zeros at the start followed by "10", then 9 bits encoding the date on which the data was collected, followed by "00000" and 24 hex digits encoding the proportion of each hour, rounded to the nearest 10%, for which the tag was dry. The last eight bits provide a simple checksum, such that dividing the data, including the checksum, into bytes and summing these, will produce a multiple of 256 if the message is uncorrupted. The hourly haulout summary encoding does not use hex values "b", "c" or "d", allowing additional checks to be made for message corruption. A full description of the data encoding is available from the tag manufacturers (Wildlife Computers, www.wildlifecomputers.com). This study uses the term "haulout message indicator" for the seven fixed bits near the start of haulout messages.

Haulout messages are stored in a buffer for twelve days and, each time the tag is ready, a message is randomly selected from this buffer for transmission. The tags only attempt to transmit when they are dry, and, to prolong battery life, these ones were set to attempt a maximum of 118 transmissions per day.

The majority of tags produced data for most days in August (Fig. S1). Multiple copies of the data for some days were received from some tags. As some of these copies differed, it is clear that some of the received messages had become corrupted. There are three ways in which this could occur, messages can be truncated or concatenated, or bits within them can be "flipped", changing their values.

A total of 5555 messages were received from the tags that contained dates in August 2009. Discarding short messages and those containing dates inconsistent with the date of their transmission left 5529 messages from 586 unique combinations of tag identity and date. The 21 that were longer than 16 bytes all began with the haulout message indicator, and so were truncated to 16 bytes. A total of 4111 of these messages then perfectly fitted the haulout-message format, which is described in the online supplementary material, reporting a date in the twelve days before transmission, and containing no impossible values in the haulout data. The remaining data provided three direct estimates of the proportion of bits that were corrupted: 2 messages claimed to contain data from the 32nd of August; 109 messages had incorrectly formed headers; and there were 906 hours within the messages for which hexadecimal values unused in the data encoding were given. All of these suggested that around 1 in 500 bits of the data were corrupted. In all the analysis that follows it is assumed that the part of the message data that contained the date was uncorrupted, since this is a small part of the message and bit-flipping within it is likely to move the apparent date outside the 12-day transmission window.

A single hexadecimal version of the data for each day was constructed with each digit being the one, out of those consistent with that position in the message format, that most of the messages for that date contained. This produced 562 records that perfectly matched the format. The reconstructed data for each of the other 24 days contains at least one error. Given the eight bit checksum and the restrictions in the message format, approximately 15% of these reconstructed messages could be expected to contain an error within the four hours around daytime low tide. These imperfectly reconstructed messages were discarded.

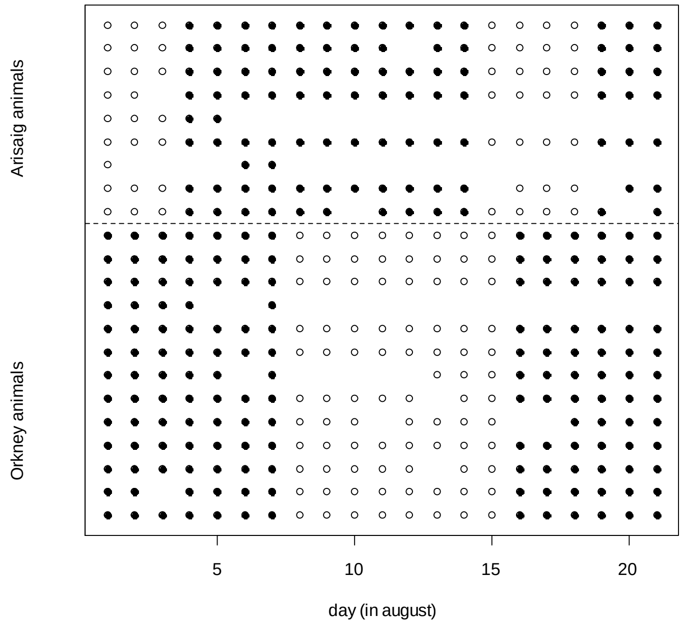


Figure S1. Data received from the electronic tags. Each row is one animal. Circles indicate days for which data is available. Solid circles are days where data was available and a low tide fell within the survey window (11:00 to 17:30 GMT). The tides at Mallaig (used for the Arisaig data, above the broken line) are approximately 7 hours after those at Kirkwall (used for the Orkney data).

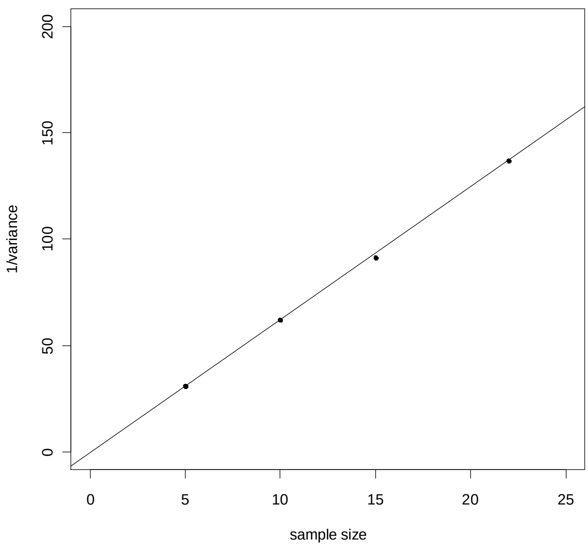


Figure S2: Scaling of variance with sample size. Each point describes the variance of a set of 10000 bootstrap samples containing a particular number of datapoints. The points all lie close to a straight line through the origin, the pattern that would be expected if stochastic variation dominated.

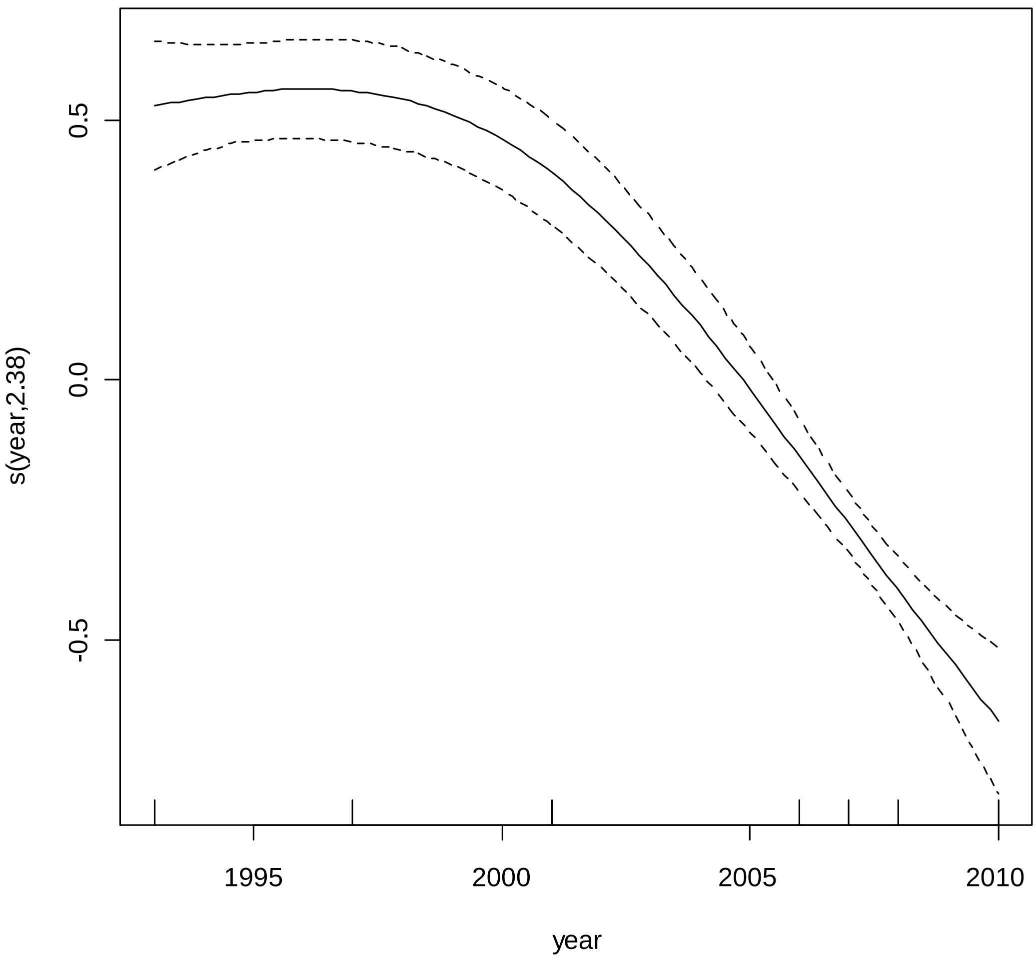


Figure S3: Plot of the smoothed population trajectory in the generalised additive model of aerial survey counts of harbour seals in Orkney. The smooth is centred and the y-axis uses the linear predictor, log, scale. Exponential trajectories therefore appear as straight lines.