Scientific Advice on Matters Related to the Management of Seal Populations: 2005

Contents

Scientific advice

Background

Under the Conservation of Seals Act 1970, 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, and information and advice in response to parliamentary questions and correspondence.

This report provides scientific advice on matters related to the management of seal populations for the year 2005. It begins with some general information on British seals, gives information on their current status, and addresses specific questions raised by the Scottish Executive Environment Rural Affairs Department (SEERAD) 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.

General information on British seals

Grey seals

The grey seal is the larger of the two species of seal that breed around the coast of the British Isles. It is found across the North Atlantic Ocean and in the Baltic Sea. There are two centres of population in the North Atlantic; one in Canada centred on Nova Scotia and the Gulf of St Lawrence and the other around the coast of the UK, especially in Scottish coastal waters. The largest population is in Canada (Figure 1). Populations in Canada, UK and the Baltic are increasing, although numbers are still relatively low in the Baltic where the population was drastically reduced by over-exploitation that took place over many decades and their recovery has been slow.

In Europe, grey seals come ashore on remote islands and coastlines to give birth to their pups in the autumn, to moult in spring, and at other times of the year to haul out and rest between foraging trips to sea for food. Female grey seals give birth to a single white-coated pup, which is nursed for a period of about three weeks before being weaned and moulting into its sea-going coat.

About 39% of the world population of grey seals is found in Britain and over 90% of British grey seals breed in Scotland (Figure 1), the majority in the Hebrides and in Orkney. There are also breeding colonies in Shetland, on the north and east coasts of mainland Britain and in Devon, Cornwall and Wales. Although the number of pups born at colonies in the Hebrides has remained approximately constant since 1992, the total number of pups born throughout Britain has grown steadily since the 1960s when records began. In 2004, there was an estimated 46,000 grey seal pups born in Britain. This is believed to equate to a total population of between 91,000 and 153,000 grey seals.

Adult male grey seals may weigh up to 350 kg and grow to over 2.3 m in length. Females are smaller, reaching a maximum of 250 kg in weight and 2 m in length. Grey seals are long-lived animals. Males will 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.

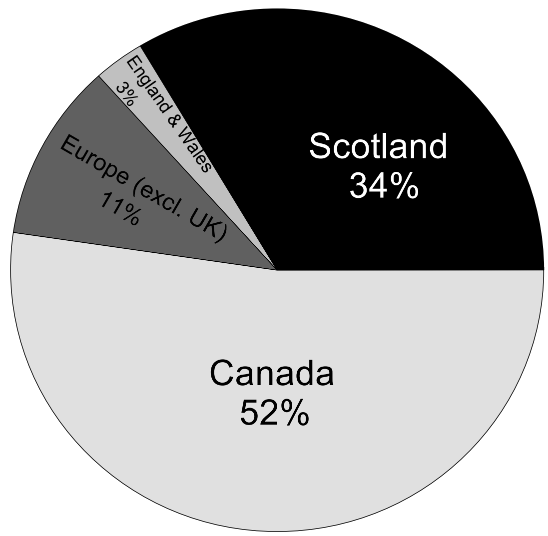


Figure 1. The relative size of the grey seal populations in the North Atlantic region, including the Baltic

Grey seals feed mostly on fish that live on or close to the seabed. The diet is composed primarily of sandeels, whitefish (cod, haddock, whiting, ling), and flatfish (plaice, sole, flounder, dab) but 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 7 kg of cod or 4 kg of sandeels per seal per day.

Grey seals often haul out on land, especially on outlying islands and remote coastlines exposed to the open sea. Tracking of individual seals has shown that they can feed up to several hundred miles offshore during foraging trips lasting several days. Individual grey seals based at a specific haul out site often make repeated trips to the same region offshore but will occasionally move to a new haulout and begin foraging in a new region. Movements of grey seals between haulouts in the North Sea and the Outer Hebrides have been recorded.

Common seals (also known as harbour seals)

Common seals are found around the coasts of the North Atlantic and North Pacific from the subtropics to the Arctic. Common seals in Europe belong to a distinct sub-species which, in addition to the UK, is found mainly in Icelandic, Norwegian, Danish, German and Dutch waters. Britain holds approximately 40% of the world population of the European sub-species (Table 1). Common 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 Wash, Firth of Tay and the Moray Firth

Between 1996 and 2004, about 33,000 common seals were counted in the whole of Britain, of which 29,500 (90%) were in Scotland and 3,500 (10%) were in England (Table 1). A total of 1,200 seals were counted in Northern Ireland (Table 1). Not all individuals in the population are counted during surveys because at any one time a proportion will be at sea. Accounting for those animals that are not seen using a conversion factor leads to an estimate for the total British population of approximately 50-60 thousand animals. 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 [1], but had limited impact elsewhere in Britain.

Common 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, common seals haul out on land regularly in a pattern that is often related to the tidal cycle. Common seal pups are born having shed their white coat and can swim almost immediately.

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

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

Table 1 Sizes and status of European populations of common seals. In most cases, numbers given predate the PDV epidemic of 2002.

Region	**Number of seals counted[1]**	**Years when latest information was obtained**	**Possible population trend[2]**
Outer Hebrides	2,000	2003	None detected
Scottish W coast	12,800	1996-2000	None detected
Scottish E coast	2,000	1996-2004	Declining in Moray Firth
Shetland	4,900	2001	None detected
Orkney	7,800	2001	None detected
Scotland	**29,500**		
England (E & S coast)	**3,500**	2001-2004	Recent decline[3]
Northern Ireland	**1,200**	2002	Decrease since 1970s
UK	**34,200**		
Ireland	2,900	2003	Unknown

[1] Thompson, D., Lonergan, M. and Duck, C. (2005) Population dynamics of harbour seals (*Phoca vitulina*) in England: monitoring population growth and catastrophic declines. *Journal of Applied Ecology* 42, 638-648.

Wadden Sea (Germany)	11,500	2000	Recent decline[3]
Wadden Sea (Netherlands)	3,300	2000	Recent decline[3]
Wadden Sea (Denmark)	2,100	2000	Recent decline[3]
Lijmfjorden (Denmark)	1,000, 500	1998-2000	Recent decline[3]
Kattegat/Skagerrak	9,800	2000	Recent decline[3]
West Baltic	300	1998	Small increase
Kalmarsund (East Baltic)	300	1998	Increasing
Norway S of 62ºN	1,200	1996-98	Unknown
Norway N of 62ºN	2,600	1994	Unknown
Iceland	19,000	?	Unknown
Barents Sea	700	?	Unknown
Europe excluding UK	**53,600**		
Total	**88,300**		

[1] – many of these estimates represent counts of seals rounded to the nearest 100. They should be considered to be minimum estimates of total population size.

[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.

Responses to questions raised by the Scottish Executive and DEFRA

In the past, the Advice from SCOS has contained annexes explaining the data used to assess the status of UK grey and common seal populations. Following the pattern first used in 2003, the structure of the Advice has changed and information about population status will now be given in response to questions from SEERAD and DEFRA. Accompanying documentation in the form of SCOS Briefing Papers (SCOS-BP) is intended to provide the additional detail necessary to understand the background for the Advice provided.

1. *What are the latest estimates of the number of seals in Scottish and English waters?* (SEERAD/DEFRA)

Current status of British grey seals

The number of pups born in a seal population can be used as an indicator of the size of the population. Each year, SMRU conducts aerial surveys of the major grey seal breeding colonies in Britain to determine the number of pups born (pup production). These sites account for about 85% of the number of pups born throughout Britain. The total number of seals associated with these 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 05/1 and SCOS-BP 05/2.

Pup production

The total number of pups born in 2004 at all annually surveyed colonies was estimated to be 39,650. Regional estimates were 3,385 in the Inner Hebrides, 12,319 in the Outer Hebrides, 19,123 in Orkney, and 4,823 at North Sea sites (including Isle of May, Fast Castle, Donna Nook and Farne Islands). A further 5,500 pups were likely to have been born at other scattered sites, including Shetland where a survey carried out in 2004 showed that pup production had not changed significantly since the previous estimate in 1977.

Trends in pup production

The differences in pup production between 2003 and 2004 are shown in Table 2. Total pup production at annually monitored colonies increased by 0.5%, in contrast to 7.4% in the previous year.

This continues a recent general pattern of increased variability in the pup production at all annually monitored colonies. The reasons for this variability are not known. It is possible that, as the population grows, breeding females become more susceptible to subtle changes in environmental factors such as food availability and that this is reflected in the increased variation in pup production.

Overall, there appears to have been a gradual decline in the rate at which pup production has been increasing over the past 10 years. In the late 1980s, pup production increased at well over 6% per annum. During the most recent 5 year period it has increased at about 1.8% per annum (see Table 2). However, there have been regional differences; pup production at colonies in the North Sea and Orkney have continued to increase and, in the case of the small and relatively new colony at Donna Nook, this has been at a rate exceeding those observed in the 1980s. At most other sites the pup production is increasing at a slower rate and pup production in the Outer Hebrides declined in the past 5 years. In 2004 there was a 10.5% decline in pup production compared with 2003. However, the 5-year mean for the Farne Islands, which is a better long-term indicator of population growth, shows a 0.5% decline in pup production.

Table 2: Grey seal pup production estimates for the main colonies surveyed in 2003

Location	2004 pup production	Change in pup production from 2003-2004	Change in pup production from 2000-2004
Inner Hebrides	3,385	<0.1%	+2.1%
Outer Hebrides	12,319	-3.3%	-1.4%
Orkney	19,123	+2.5%	+0.8%
Isle of May + Fast Castle	2,612	+0.5%	+2.2%
All other colonies	3,672		
Total (Scotland)	41,111		
Donna Nook	1,078	+36.1%	+14.3%
Farne Islands	1,133	-10.5%	-0.5%
SW England & Wales (last surveyed 1994)	1,750		
Total (England & Wales)	3,961		
Total (UK)	45,072	+0.5%*	+1.8%

*Annual change in pup production calculated from annually monitored sites only

Population size

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

The recent decline in pup production could be a result of reductions in the reproductive rate and/or survival of pups or adults (SCOS-BP 05/2). There is a lack of independent data by which we can quantify the relative contributions of these factors. The current analysis of changes in pup production at individual colonies uses 4 different models of the processes underlying changes in population size. The four models fit similarly well to the data on observed changes in pup production (SCOS-BP 05/2) but give different population estimates (range 104,000 – 234,000). If a decline in reproductive rate is assumed to be behind reductions in pup production, the estimates of current reproductive rate are much lower than those that have been observed at individual colonies (SCOS-BP 03/6). If instead a decline in pup survival is assumed to be the mechanism behind changes in population growth, the estimates of current pup survival are within the observed range. For these reasons, we use the population estimate based on density-dependent pup survival in this Advice. It is now a research priority to improve our understanding of the processes underlying density-dependent population change in the grey seal population, and to obtain an independent estimate of total population size that does not rely on modelling the relationship between population size and pup production.

Consequently, our best estimate of current population size associated with the regularly surveyed colonies using the approach that has been used for the last 2-3 years – i.e. assuming that population growth has slowed because of increased juvenile mortality - is 78,000 – 141,000. Seals from sites that are monitored less often add another 17,000 to this total. These data suggest an increase of about 2.7% over the population size in 2003 estimated using the same methods. The majority of these seals, approximately 92%, are associated with colonies in Scotland and the remaining 8%, with colonies in England and Wales.

Uncertainty in the estimates

Besides the uncertainty associated with which model to use in the calculation of the total population size, there are uncertainties associated with the estimates of pup production, which are believed to lie within a range of –10% to +13% of the values provided. However, the population modelling described in SCOS-BP 05/2 indicates that the true level of uncertainty may be even greater than this. A new approach to estimating total pup production is being investigated (see SCOS-BP 04/3). Even when this approach is implemented, unknown uncertainties associated with the estimates of pup production at colonies that are not surveyed annually will remain. These also have to be combined with the uncertainties about the value used for adult male survival, about which little is known.

Trends in population size

There is now convincing evidence that the growth of pup production in the Inner and Outer Hebrides has slowed substantially (SCOS-BP 05/1). However, even if this trend continues, the British grey seal population as a whole is likely to continue increasing for some years (see SCOS-BP 03/3) because there is a time lag in changes in pup production being translated into changes in population size.

<u>Current status of British common seals</u>

Each year SMRU carries out surveys of common seals during the moult in August. Recent survey counts and overall estimates are summarised in SCOS-BP 05/4. It is impractical to survey the whole coastline every year but current plans by SMRU are to survey the whole coastline across 5 consecutive years. Seals spend the largest proportion of their time on land during 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 in The Wash. Additional surveys using visual counts are conducted annually in the Inner Moray Firth by the University of Aberdeen.

The estimated number of seals in a population based on most of 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. About 40% of common seals are likely not to be counted during surveys but because of the uncertainties involved in the surveys, the counts are normally presented as minimum estimates of population size. It is on this basis that the most recent count totalling about 34,000 common seals in the UK is likely to indicate a total population of 50,000-60,000 seals.

Apart from the population in The Wash, common 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. However, again The Wash was most the most affected region and counts in 2004 suggested a continued decline following the epidemic.

Counts by region are given in the Table 4 below**.** These are minimum estimates of the British common seal population.

Table 4 Counts of common seals by region

Region	**1996-2004**
Shetland	4,883
Orkney	7,752
Outer Hebrides	2,098
Highland (Nairn to Cape Wrath)	1,232
Highland (Cape Wrath to Appin & Loch Linnhe)	4,947
Strathclyde (Appin to Mull of Kintyre)	6,918
Strathclyde, Firth of Clyde (Mull of Kintyre to Loch Ryan)	991
Dumfries & Galloway (Loch Ryan to English Border at Carlisle)	6
Grampian (Montrose to Nairn)	113
Tayside (Newburgh to Montrose)	121
Fife (Kincardine Bridge to Newburgh)	414
Lothian (Torness Power Station to Kincardine Bridge)	40
Borders (Berwick upon Tweed to Torness Power Station)	0
TOTAL SCOTLAND	**29,515**
Blakney Point	715
The Wash	2,167
Donna Nook	346
Scroby Sands	65
Other east coast sites	225
South and west England (estimated)	20
TOTAL ENGLAND	**3,573**
TOTAL BRITAIN	**33,052**
TOTAL NORTHERN IRELAND	**1,248**
TOTAL BRITAIN & NORTHERN IRELAND	**34,300**
TOTAL REPUBLIC OF IRELAND	**2,905**
TOTAL FOR GREAT BRITAIN AND IRELAND	**37,205**

2. *What is known about the population structure of grey and common seals in European and Scottish waters? Is there any evidence of populations or sub-populations specific to local areas?* (SEERAD/DEFRA)

Grey seals

Within Europe there is a clear genetic and behavioural distinction between the grey seal population that breeds within the Baltic Sea and those populations breeding elsewhere[2]. The vast majority (85%) of grey seals breeding outside the Baltic breed around Britain. Within Britain there is again a clear genetic distinction between those seals that breed in the southwest (Devon, Cornwall and Wales) and those breeding around Scotland and in the North Sea[3]. 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.

In 2003 work began to develop a spatially-explicit model of the British grey seal population. 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 conclusion is supported by the results of detailed studies at breeding colonies and resightings of individual seals that had been photo-identified. These studies have indicated that breeding females tend to return to their natal breeding colony and remain faithful to that colony for most of their lives.

Common seals

Samples from seals in Northern Ireland, the west and east coasts of Scotland, the east coast of England, the Dutch and German Waddensea, the Kattegat/Skagerrak, Norway, the Baltic Sea and Iceland have been subjected to genetic analysis. This analysis suggested that there are genetically distinct common seal populations in European waters[4]. There is probably very little movement of breeding animals between these populations. 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. Similarly, studies of the movements of branded seals in the Kattegat/Skagerrak[5] indicate that there is only limited movement within the western Scandinavia population. However, in both 1988 and 2002 phocine distemper spread rapidly among European common seal populations, suggesting that substantial movement of individuals can occur, although the genetics studies suggest these movements do not usually result in seals reproducing in locations they visit temporarily.

---

[2] Graves, J.A., Helyar, A., Biuw, M., Jüssi, M., Jüssi, I. & Karlsson, O. (submitted) Analysis of microsatellite and mitochondrial DNA in grey seals from 3 breeding areas in the Baltic Sea. *Conservation Biology*

[3] SMRU unpublished data

[4] 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.

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

Current work
Work is currently being done to develop spatial management units and to connect these to population structure. This is partly built from studies of movements and habitat use (SCOS-BP 05/03 and 05/05). One current approach to using current knowledge about population structure in management is provided in SCOS-BP 05/8.

3. What is the latest estimate of consumption of fish by seals in Scottish waters? (SEERAD)

A study is nearing completion that will produce estimates of diet composition and consumption of fish by grey seals for the year 2002. The study is funded by DEFRA, SEERAD and SNH and relates to the Inner and Outer Hebrides, Orkney, Shetland and the east coast of Britain. On-going analysis of information from telemetry studies will provide a basis for estimating fish consumption by seals in different regions of Scotland. However, until final results are available, calculations of the consumption of fish by grey seals in Scottish waters have been based on previous estimates of diet composition and the most recent estimates of population size.

Total fish consumption depends on the proportion of the diet that is composed of fish and the type of fish consumed. For the purposes of this calculation, it is assumed that sources of food, other than fish, such as crustaceans and molluscs (including squid), make an insignificant contribution to the diet.

Grey seals
Based upon the total energy requirements calculated in SCOS-BP 03/9 and the population estimates based on the density-dependent survival model of population size, the annual food consumption of grey seals in Scotland would be between 81,000 and 141,000 tonnes of fatty fish, such as sandeels, herring or mackerel. Alternatively, if these seals ate only whitefish then the annual consumption would be between 150,000 to 262,000 tonnes.

Common seals
Information about the total prey consumption of the Scottish common seal populations is less advanced. However, based upon current knowledge of the likely daily ration of about 3 kg of fatty fish per day or up to 5 kg of whitefish per day, the consumption by common seals in Scotland would be between 49,000 and 60,000 tonnes if the diet was entirely composed of fatty fish and 82,000 and 100,000 tonnes if the diet was entirely composed of whitefish.

Total for Scotland
Overall, the consumption of fish by seals in Scottish waters is likely to lie in the range 130,000 to 362,000 tonnes. The greatest uncertainties in this calculation are caused by lack of knowledge of diet and uncertainties in the population estimates. If we use the estimate of diet composition from the mid 1980s as an indication of diet composition today, the total annual fish consumption is likely to lie between 180,000 and 255,000 tonnes.

4. Have there been any recent developments, in relation to non-lethal methods of seal population control, which mean that they could now effectively be applied to Scottish seal populations where appropriate? (SEERAD/DEFRA)

Controlling seal populations could be achieved by non-lethal reduction of the birth rate or by excluding seals from sensitive habitats and regions. Although these have been attempted on a trial basis or on small scales in the past, there is no new information to suggest that a breakthrough has been made in the technology or methodology associated with either approach.

SCOS BP 05/6 provides information about current research, funded by SEERAD, being undertaken to use acoustic deterrent devices (ADDs) to exclude seals from sensitive regions.

General

5. In light of developments since 1994, can SCOS review the desk study to investigate the application of non-lethal immunological methods of population control to Scottish seal populations and identify which of the six issues, listed in the SCOS Report 2004, remain to be addressed? (SEERAD)

Application to Scottish seal populations

The Advice provided in 2004 pointed out the issues raised by a desk study[6] carried out in 1994 to investigate non-lethal method of population control. These issues were:

1. Availability of appropriate drugs or techniques;
2. Delivery mechanisms;
3. Assessment of the effectiveness of the treatment;
4. Assessment of the side effects of the treatment;
5. Human safety and, in particular, the effects within the food chain;
6. Cost-effectiveness

With respect to seals, the development of immunocontraception since the report was written in 1994 has probably addressed all of these concerns except that of cost and the effectiveness of the treatment. The treatment has been shown to be effective at the level of individual seals but there are important barriers to its practicality as a tool for controlling the grey seal population in the UK.

The method could only be applied in practice to female grey seals when they are at their breeding colonies. Consequent disturbance at breeding colonies could be severe because mothers will abandon their pups and may be encouraged to disperse to establish new colonies. This leads to welfare issues, and may even lead to an increase in population growth rate as new colonies establish. Hence immunocontraception is not a practical method of controlling the UK grey seal population.

Immunocontraception is also unlikely to be a cost-efficient methods of controlling common seals because of the large investment that would be required to capture common seals.

6. Is there any indication that climate change is affecting either common (harbour) and/or grey seal populations in the UK? (SEERAD)

Since seals feed at the upper levels of marine food chains there is a strong likelihood that they will be affected by changes in the distribution and abundance of food that could result from

[6] Gardiner, K.J., Racey, P.A. & Hiby, L. (1994) Population management of seals: an evaluation of non-lethal methods of population control. Report to Ministry of Agriculture Fisheries and Food, 8 pp.

climate change and the resultant changes in the structure of the coastal seas around the UK. There is an expanding body of evidence showing that seals may respond to climate fluctuations and regime shifts in the oceans. These responses are usually manifest in the form of changes in reproductive success and pup survival rate.

As reported above, grey seal pup production at annually-monitored sites appears to have exhibited an increasing level of inter-annual variation in recent years (SCOS-BP 05/1). This may be caused by the population approaching the environmental carrying capacity and, therefore, showing greater sensitivity to annual fluctuations in the availability of prey. To date, no analysis has been able to demonstrate a convincing relationship between this pattern of fluctuation and measurements of food availability or direct measures of climate fluctuation. Therefore, there is no direct evidence that current population trends and variation in UK seals are affected by climate change.

7. What are the likely responses of common (harbour) and/or grey seals to climatic change? (SEERAD)

Based upon information provided by the UK Climate Impact Programme Scenarios (http://www.ukcip.org.uk/), over the coming century we expect that in the UK:

- temperatures will increase
- winter rainfall will get heavier
- summer rainfall may reduce considerably
- sea levels will rise.

Seals will respond to the effects of climate change through (1) adaptive responses in their physiology because of changes in the magnitude of physical stresses, mainly associated with temperature; (2) behavioural responses associated with the selection of appropriate habitat; and (3) energetic responses caused by changes in the availability of food. All of these could have consequence for the distribution and abundance of seals in the UK.

Prediction of the response of common or grey seals to climate change depends upon being able to test appropriate models of each of these processes by fitting them to data. Models that provide a good representation of the data have the potential to predict how the population may respond to climate change. As a result of this process, we have a better understanding of physiological than behavioural responses. We have the poorest ability to predict the responses at a population level because these depend upon how climate change will affect food distribution and abundance, which cannot be predicted within useful bounds of certainty, and because responses at the population level are the summed responses of many individuals.

Examples of the types of responses that can be expected are as follows:

1. Both common and grey seals are distributed across a broad latitudinal range representing Arctic to cool temperature regions. This suggests that they are likely to have relatively high tolerance to temperature increase of the magnitudes expected as a result of climate change. However, as with many other species[7], it is possible that seals may gradually shift their range

[7] Perry AL, Low PJ, Ellis JR, Reynolds JD (2005) Climate change and distribution shifts in marine fishes, Science 308 (5730): 1912-1915

north as temperatures warm. In the case of seals these shift are more likely to occur because of changes in the distribution of prey species than because of the physiological tolerance of the seals to changes in temperature or rainfall.

2. Seals spend significant proportions of their time out of the water. The magnitude of changes in mean water or air temperatures predicted to take place as a result of climate change are well within the thermo-neutral zone of both species of seals in the UK but it is likely that there will be an increasing frequency of air temperatures that exceed the thermo-neutral zone for seals in air. The likely response to this is that seals will enter the water and spend less time hauled out.

3. Pups are particularly vulnerable to thermal stress. It is possible that increased water and air temperatures, and changing patterns of rainfall, during the breeding period will change thermal stress on pups and could lead to changes survival rate, but there are no quantitative data to assess the magnitude of such an effect. In general, we would expect increases in temperature to result in higher pup survival rate but this could be counterbalanced in grey seals by higher winter rainfall since wetting of pups during the early post-natal period is likely to exacerbate heat loss.

4. Some evidence suggests that seals avoid thermal stress on hot days by entering the water. The structure of some grey seal colonies is influenced by the presence of pools of water which animals may use to help alleviate thermal stress. Changes in the size and occurrence of pools as a result of varying rainfall can influence the suitability of the habitat for breeding grey seals. Higher temperatures may also lead to a greater need for grey seals to have access to pools on breeding colonies and, unless these are available, it is possible that some areas occupied by breeding grey seals could be abandoned. Conversely, increased winter rainfall may improve habitat quality for breeding grey seals by increasing the number and size of pools.

5. On a longer time scale, sea level changes could have a significant effect upon the suitability of current habitat for seals. Seals use tidal islands for resting and breeding and many of these will no longer be available if predicted sea level rise comes about. Further work would be required to understand the effects of different magnitudes of sea level change upon the availability of haul-out habitat.

6. Because these species feed at depths that are at least an order of magnitude greater than the predicted increase in sea level, effects on the access to suitable feeding habitat are likely to be small. However, even relatively small changes in the depth of prey could translate into important consequences for the trajectory of the population.

7. Although it is not possible to say what effect climate change will have on the availability of prey species, changes in the food web structure, possibly as a result of local climate change in the North Pacific, is one of the principal candidates explaining the recent decline of the Steller sea lion. Modelling has shown that apparently small changes in the accessibility of prey as a result of such structural changes can produce the kind of effects observed in Steller sea lion populations.

8. Changes in the movement pattern of seals resulting from climate change could result in changes in the susceptibility of populations to disease. Since the spread of disease depends greatly upon the extent of movement of infectious individuals, any factors that are likely to increase migratory movement or foraging ranges could reduce the threshold level of infection for

the spread of disease. However, it is not possible to predict at this stage what effect, if any, climate change may have upon movement and, by implication, the susceptibility to disease.

8. What kind of additional strategic research on seals might be done that would ultimately inform future management policy? (SEERAD/DEFRA)

Current specific short-term issues requiring particular attention are:

1) Estimation of the diet of harbour seals;
2) Provision of an estimate of grey seal population size using a method that is independent of estimates of pup production (see above)
3) Understanding spatial structure within seal populations in order to contribute to management planning;
4) Mapping the distribution of seals in relation to fish distributions and fisheries, in order better to understand seal/fishery interactions.

The broader requirements for strategic research can be divided into three categories; (i) long-term monitoring and data collection; (ii) underpinning science and (iii) emerging issues. Strategic research needs to be structured to be able to support these three categories for both UK seal species.

(i) Long-term monitoring and data collection should include the measurement of:

- the size and status of UK seal populations;
- seal life-history variables;
- seal diet;
- population health status.

(ii) Research needs to include:

- developing and fitting population models;
- developing and fitting models of foraging and habitat selection;
- developing and fitting models of how changes in food abundance, quality and distribution influence diet, reproduction, growth and, ultimately, the population trajectory;
- improving knowledge of population structure, genetics and factors affecting survival and fecundity.

(iii) There is a need for capacity to respond to emerging issues including:

- Seal interactions with aquaculture;
- Seal interactions with seismics/acoustics;
- Seal interactions with offshore fossil fuels/renewables;
- SAC monitoring;
- Interactions of top predators within ecosystem;
- Interactions with fishing gear – bycatch, ghost fishing.

9. There is a increasing need to develop suitable management units for seals around Scotland to allow consistent monitoring, reporting and management of seals to be undertaken (i.e. on the lines developed under the Moray Firth Plan). What principles should be used to define

such management units elsewhere in Scotland for both common (harbour) and grey seals and what might these management units be? (SEERAD)

Management should ideally be focussed upon biologically meaningful populations in which there is a clear boundary, normally geographical, across which it is possible to estimate immigration and emigration rates. Management also needs to refer to current regions in which there is some form of legal protection (SCOS-BP 05/10). Ideally, we would wish to define management units that minimised the transfer across boundaries between these units. Distance between centres of population, such as breeding colonies, may be a good indicator of the relative degree of reproductive isolation but the scale of the distances will probably vary between species. For example, current data suggest grey seals move over greater distances than common seals (SCOS-BP 05/5 and SCOS-BP 05/3). There is also a distinction between how management units may be defined for grey seals and common seals because grey seals tend to breed at specific, well-defined locations (colonies) whereas common seal breeding is much more dispersed. In contrast, common seals seem to display greater fidelity to defined regions, such as river estuaries, throughout the year than grey seals.

Grey seals
We know that individual adult female grey seals show high fidelity to breeding in particular locations year-on-year. There is also evidence that, even amongst juveniles, when dispersal occurs there is a tendency to recruit in neighbouring colonies to the colony of birth rather than to recruit randomly to colonies anywhere in Britain. For example, the history of colonisation in the North Sea and in Orkney has shown that as one colony is filled apparently to capacity, new colonies tend to develop and fill up nearby. Thus the historical pattern of spread of grey seals from the early centres of breeding, such as Lunga (Inner Hebrides); North Rona (Outer Hebrides); Muckle Greenholm (Orkney); and the Farne Islands (North Sea) is likely to be a good indicator of the present population structure. The presentation of population data for grey seals in this Advice has traditionally followed these boundaries because they represent the historical founder groups and it would be reasonable to continue to view these as appropriate management units, with the addition of those in Wales as a distinct grouping. However, it should be noted that the foraging regions for seals from each of these groups can have considerable overlap. For example, a grey seal in the Moray Firth is most likely to come from those breeding in the North Sea or Orkney. It is less likely to come from the Hebrides and very unlikely to come from Wales. With further work, it would be possible to use tracking data for grey seals from each region to help estimate the probabilities associated with encountering grey seals from each region foraging within another region.

Common seals
Our knowledge of common seal distributions is largely developed from information about where they haul out, although this has been augmented in the last two years with increasing amounts of data about movements (SCOS-BP 05/5). Although common seals seem to show some fidelity to particular haul-outs, they occasionally make rapid, relatively long-distance movements to other haul-outs. These “jumps” can be viewed in terms of probabilities that appears to be a function of distance. There may, therefore, be some justification for defining management units for common seals in relation to centres of relatively high population density. Examples would include The Wash, Firth of Tay, Moray Firth, Orkney and Shetland. Problems mainly arise within the Hebrides which is a relatively large region in which common seals are found throughout at comparatively high densities. Any sub-division of the Hebrides would probably have to include a degree of convenience and artificiality, for example, by distinguishing between Outer and Inner Hebrides and perhaps by dividing the Inner Hebrides into the northern region including Skye, Small Isles, Tiree and Coll and the southern or nearshore group including Mull, Firth of Lorn,

Colonsay, Islay and Jura. SCOS-BP 05/7 shows a suggested distribution of management units. As is the case for grey seals, further work would be required to define the extent to which seals from one area are likely to occur in another; some data are already available to help with this process (see SCOS-BP 05/8).

10. In 2004, the ICES Working Group on Marine Mammal Ecology recommended to OSPAR (Oslo and Paris Commission) that seal population trends provided a useful Ecological Quality Element for North Sea populations. The pilot EcoQO (Ecological Quality Objective) for both common (harbour) and grey seals in the North Sea was defined as, "No decline in population size or pup production of 10% over a period of up to 10 years". How suitable for their purpose are these EcoQOs as currently configured? (SEERAD)

The EcoQO as currently defined is arbitrary because it has not been formally constructed around the demographics of seal populations or the normal level of variability that could be expected in seal population trajectories. However, it remains problematic to construct something more appropriate when the purpose of EcoQOs is not well defined. Seals themselves may not be sensitive indicators of the kind of ecological effects of interest to OSPAR but they are a group for which there is a large amount of background information and which attracts a high level of public interest. If this EcoQO is intended to be used as a trigger for management action then we recommend that before deciding on the final formulation it should be the subject of a simulation study using the historical time-series of data from the UK seal population. This should include an analysis of the probability of detecting trends of the type currently defined within current levels of measurement uncertainty. At various times in the future, such an arbitrary measure may prove to be too sensitive, especially since pup production is likely to be much more variable than the population size as a whole. It may also be wise to consider a formulation of the EcoQO that considers what sustained positive growth in the population says about ecological quality.

Moray Firth

11. What recent developments have there been in relation to the calculation of Permitted/Potential Biological Removals (PBR) that SEERAD should be aware of either in relation to the Moray Firth or more generally? (SEERAD)

There have been no recent developments in the context of PBR calculations.

12. How might the historical data provided by FRS-ML on the shooting of local seal populations be used to improve seal population modelling? (SEERAD)

The question refers to historical data on the shooting of seals in the Moray Firth. Two different sets of data are available:

Before 1983, data were compiled from information about the rewards provided to fisheries managers on production of a seal tail. Data from 1994 to the present were compiled as part of the Moray Firth Sea Management Plan. These represent a collation of records kept informally by salmon fisheries managers and by salmon farms in the region.

In other regions, numbers of seals shot have been used to reconstruct the population. However, in this case there are several important problems with the historical data that mean this is not possible:

(i) Before 1983, no information was collected about the species being shot. From 1994 some information about species was provided but, in some years, most seals were not identified to species and the reliability of the reported species identifications is questionable. Therefore, we cannot say how many common seals were being killed.

(ii) A proportion of carcases sinks when seals are shot making the tail unrecoverable. Therefore, the number of seals recorded as being shot before 1983 is likely to be an under-estimate of the total number.

When combined, these complications make it very difficult to interpretation the data collected before 1983. In addition, independent counts of seals in the region only began in 1988 so data about the number of seals shot before these records began could not be used to model the population.

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 Executive and the Home Office on questions relating to the status of grey and common 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 IL Boyd, University of St Andrews;
Dr T Coulson, University of Cambridge;
Dr K. Kovacs, Norwegian Polar Institute, Tromso, Norway;
Professor A. Thorpe, Chief Executive, NERC, Swindon;
Dr J. Armstrong, FRS Laboratory, Pitlochry;
Professor Marc Mangel, University of California, Santa Cruz;
Dr EJ Milner-Gulland (Chair), Imperial College, London;
Dr J. Pinnegar, CEFAS, Lowestoft;
Professor W Sutherland, University of East Anglia;
Professor PM Thompson, University of Aberdeen;
Katherine Branch (Secretary), NERC, Swindon.

ANNEX II

Briefing papers for SCOS

Until 2003, additional information has been appended to the draft Advice in two forms. One of these concerned the status and trends of grey and common seal populations and this had been presented as annexes to the Advice. The other had been a set of ad-hoc information papers. The Annexes had normally been unattributed and had formed a part of the Advice. In addition, SCOS had usually been provided with several verbal presentations of work in progress.

The structure piloted in 2003 is being used again on 2004. The Annexes and the information papers have been combined into one format known as a *briefing paper*. The intention is to ensure that the science underpinning the Advice is made more transparent and is provided in more detail but also in a format that encourages rapid assimilation of the essential information. This is necessary because, with the current structures for considering the Advice as described in SCOS (SCOS-BP 03/1), there is likely to be increased scrutiny of the outputs from SCOS. *Briefing papers* will provide up-to-date information from the scientists involved in the research and will be attributed to those scientists. It is hoped that scientists who have not traditionally been involved in SCOS might also be willing to contribute by providing briefing papers. .

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, 2005.

05/01 Grey seal pup production in Britain in 2004.
C.D. Duck and B.L. Mackey

05/02 Estimates of grey seal population size 1984-2004.
L. Thomas and J. Harwood

05/03 Update on the distribution of grey seals outside the breeding season
J. Matthiopoulos and G. Aarts

05/04 The Status of British Common Seal Populations
C.D. Duck, D. Thompson & L. Cunningham

05/05 Distribution and movements of harbour seals around the UK
Sharples, R. J., Cunningham, L. and Hammond P.S.

05/06 Current research being undertaken into seal-salmon interactions in freshwater in the Moray Firth
I.M. Graham, R.N. Harris, C.D. Duck and I.L. Boyd

05/07 Population assessment methods of harbour seals.
L. Cunningham and C. Duck

05/08 Defining management areas for seals in Scotland
C.D. Duck, B.L. Mackey and J. Matthiopoulos

05/09 The Potential Impact Of Removing Seal Predation From Atlantic Salmon Rivers: The Relevance Of Salmon Population Scale
I.M. Graham, S.J. Middlemas (FRS), J.R.A. Butler (Spey Board), P.M. Thompson (Univ. Aberdeen) and J.D. Armstrong (FRS)

05/10 Reporting on grey and common seal interest features of Special Areas of Conservation in Scotland.
Scottish Natural Heritage

C.D. Duck and B.L. Mackey

Grey seal pup production in Britain in 2004

NERC Sea Mammal Research Unit, Gatty Marine Laboratory, University of St Andrews, St Andrews KY16 8LB

1. Surveys conducted in 2004

Each year SMRU conducts aerial surveys of the major grey seal breeding colonies in Britain (Scotland) to determine the number of pups born. In addition, new locations where grey seal pups have been seen or reported, or which appear to be suitable for colonization, are visited regularly. During the 2004 breeding season, between four and six surveys were flown over the main colonies in the Inner and Outer Hebrides, Orkney and the Firth of Forth. There was a major effort to determine the grey seal pup production in Shetland using boat and ground counts in collaboration with Scottish Natural Heritage (SNH). This was the first comprehensive survey of breeding colonies in Shetland since 1977.

Both Linhof cameras developed faults during the aerial survey. Both film transport magazines failed and, more importantly, the shutter failed on one camera. This failure resulted in two counts of the Isle of May and Fast Castle being missed and one count of a number of colonies in Orkney. In addition, some photographs were uncountable due to excessive film or camera movement during shutter release. This problem affected six films and the cause has not been identified. However, it appears that the problem has been resolved as the last 15 films showed no sign of movement. Fortunately, a number of the islands affected were peripheral colonies (Sound of Harris Islands, Muck, the Ascrib Islands and Canna) and not part of the annually monitored group of colonies.

In summary, one of the Inner Hebrides colonies had three counts, the remaining 10 had four; in the Outer Hebrides, nine colonies had three counts, two had four counts and two (Ceann Iar and Mingulay) had five; Orkney colonies had either four or five counts; the Isle of May and Fast Castle each had three useable counts out of six flights. There were two counts of a new colony in Orkney.

National Trust staff counted pups born at the Farne Islands and at a new colony at Blakeney Point in Norfolk. Staff of the Lincolnshire Wildlife Trust counted pups born at Donna Nook and Scottish Natural Heritage staff counted pups born on South Ronaldsay. It may not be possible for SNH to obtain counts for South Ronaldsay in 2005 as the staff member responsible for the counts is expecting her first offspring in late October.

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

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 development of pups. The method used to obtain the estimates for the 2004 pup production was similar to that used in previous years. A lognormal distribution was fitted to colonies surveyed four or more times and a normal distribution to colonies surveyed only three times. Different analyses were required due to the camera problems described previously.

Total pup production in 2004 at all annually monitored colonies was estimated to be 39,650, an increase of 0.5% from the 2003 production of 39,436 (Table 1). The trajectory of pup production, with 95% confidence limits, at the major breeding colonies in England and Scotland (excluding Loch Eriboll, Helmsdale and Shetland) between 1984 and 2004 is shown in Figure 2a. Figure 2b shows the pup production trajectories at the main island groups from 1960 to 2004. Production from the main island groups is shown in more detail in Figure 3a (Inner and Outer Hebrides and Orkney) and in Figure 3b (North Sea colonies; Blakeney Point was included with Donna Nook). The time series of production estimates for these four island groups is given in Table 4.

In 2003 the confidence limits for the Outer Hebrides production were unusually large (Figure 3a) due to four lost films and missing the first counts. The confidence limits for 2004 for all island groups were considerably smaller, even though the number of usable counts was reduced to three for many colonies.

For colonies not surveyed by air, pups were counted directly from the ground. These counts are conducted annually at the Farne Islands, Donna Nook and South Ronaldsay in Orkney but less frequently at SW England and Wales. National Trust staff will count pups annually at the new Blakeney Point colony. SNH staff count South Ronaldsay pups in a manner compatible with counts from aerially surveyed colonies. South Ronaldsay data have been included with the main Orkney production estimates.

The new colonies in the Outer Hebrides and Orkney which were included in Table 2 for the first time, are monitored annually. However weather conditions and camera failure resulted in only two counts for Berneray, so the higher count has been included in Table 2. One new colony in Orkney was surveyed three times but on the first flight the camera shutter failed so only two counts were available. The higher count for this colony, at the south end of Rothiesholm on Stronsay, is included in Table 5.

3. Trends in pup production

The differences in pup production at the main island groups are shown in Table 1. Total pup production at annually monitored colonies increased by +0.5% overall; the change varying from –10.5% at the Farne Islands to +36.1% at Donna Nook (however, excluding Blakeney Point, the increase at Donna Nook was 26.0%).

Thus the results from 2004 continue to support the trends observed in recent years. The rate of increase in grey seal pup production is not as high as it was during the late 1980s and early 1990s, with the exception of the steadily increasing (but still relatively small) colony at Donna Nook (Table 2). The rate of increase in production in Orkney is lower than in previous years (Tables 1 and 2).

Table 1. The percentage change in grey seal pup production at annually surveyed colonies in the main island groups between 2003 and 2004 with the overall annual change over the previous five years (2000 and 2004).

Location	**Change 2003-2004**	**Overall annual change 2000-2004**
Inner Hebrides	0%	+2.1%
Outer Hebrides	-3.1%	-1.4%
Orkney	+2.5%	+0.8%
Isle of May & Fast Castle	+0.5%	+2.2%
Farne Islands	-10.5%	-0.5%
Donna Nook & Blakeney Point	+36.1%	+14.3%
Total	**+0.5%**	**+1.8%**

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). There were further declines in pup production in 1997 (mainly due to a reduction in the number of pups born in the Outer Hebrides), 1999 (in all island groups) and in 2002 (again, mainly in the Outer Hebrides). In the years following each of these declines, there was a marked increase in total pup production (by 9.5%, 11.5% and 7.4% in 1998, 2000 and 2003 respectively).

The overall annual percentage change in pup production at each of the main island groups between 2000 and 2004 is shown in Tables 1 and 2. These changes varied from –1.4% at the Outer Hebrides to +14.3% at the small colony at Donna Nook (including Blakeney Point). The overall change, for all colonies combined, was +1.8%. Changes for the two preceding five year intervals are shown for comparison in Table 2.

Pup production fluctuates between years but since 1996, the fluctuations have been more variable than previously (Figures 2a and 2b). This is also reflected in the annual rate of change in production between years. It is difficult to determine what causes these changes but they could indicate that the grey seal population is approaching the limits of size. To even out these fluctuations, the average percentage rate of annual change in pup production for five yearly intervals since 1990 are shown in Table 2. These figures are probably the best indication of the current trends in 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.

In previous versions of this Advice, we have 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.

5. Confidence limits

Ninety-five percent confidence limits on the pup production estimates varied from being within 2.1% of the point estimate in Orkney to 4.9% in the Inner Hebrides (Figures 3a and 3b).

6. Pup production at colonies less frequently surveyed

Approximately 15% of all pups are born at these colonies each year (Tables 3 and 5). Confidence limits cannot be calculated for these estimates because they represent single counts. In 2004, Loch Eriboll and Eilean nan Ron (Tongue) were surveyed three times and production estimated using a normal distribution. The results are in Table 3. Table 3 also includes the total counts from the colonies listed in Table 5 (under Other colonies). These and other potential breeding locations are checked when flying time, weather conditions and additional circumstances permit. Table 3 indicates that approximately 5,300 pups were born at colonies not surveyed annually.

7. Pup production in Shetland

Boat and ground counts of breeding colonies in Shetland were carried out by a team of volunteers organized by SMRU and SNH staff. The survey coordinators were Rob Harris (SMRU), Paul Fisher (local) and Karen Hall (SNH Shetland).

Five colonies were counted three times or more and for these, pup production was estimated using the standard SMRU model (Table 6) with a normally distributed birth curve. A further five colonies were counted once or twice due to limited accessibility, either because of topography or location or weather conditions. For these colonies, the maximum count has been used. The model was run using both a 50% moulter classification and a 90% classification. The latter produced considerably better fits with lower confidence intervals. Both production estimates are included in Table 6. We recommend that the 90% moulter classification productions should be used. This is because moulted pups are more likely to be correctly classified during ground counts because the counters are relatively close to the pups and can assess accurately whether a pup has fully moulted or not.

The minimum pup production for Shetland in 2004 was 943 pups. All the maximum counts for colonies in Table 6 are probably lower than the true production, thus annual pup production in Shetland is likely to be slightly more than 1,000. This figure is remarkably close to the production calculated from the 1977 survey (1,000 pups). This may be a consequence of the restricted and exposed nature of the breeding colonies in Shetland which may limit colony expansion.

The biggest colony in Shetland, at Uyea, was only counted once during the breeding season. This was because the area can only be accessed by boat and unfavourable weather conditions and boat operating restrictions prevented further surveys. It might be possible, during the 2005 breeding season or in the near future, to concentrate all survey effort on this one colony to obtain at least three counts. In addition, it might be possible to begin an annual survey of pups born on Mousa. SNH are interested in establishing a regular grey seal monitoring programme and Mousa, with its easy access, is an ideal colony.

8. Proposed surveys for 2005

In the 2005 breeding season, we propose to continue the current survey protocol but to obtain at least five, preferably six, counts for each colony. This will minimally increase the survey cost over that for 2004, when colonies were photographed either five or six times.

9. Acknowledgements

Thanks to all those who provided or helped collect the data presented in this report. These include John Walton (Farne Islands), Rob Lidstone-Scott (Donna Nook), David Wood (Blakeney Point), Ron Morris and Dave Jones of the Forth Seabird Group (Forth inner islands), Britt Bezemer and Geert Aarts (SMRU aerial survey), Bill Giles and Peter Holt (pilots). The 2004 Shetland grey seal survey was only completed due to the exceptional efforts of a number of people. These include Rob Harris, Paul Fisher, Catriona Stephenson, Karen Hall, Howard Towll, A Prior, K Passfield, G Hughes, N Davies, A Taylor, P Ellis, H Moncrieff, P Harvey, T Ash, Malkie, P French, R Riddington, S Smith, M Fisher and J Wills.

Table 2. Pup production estimates for colonies in the main island groups surveyed in 2004. The overall 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 estimates for the Isle of May, Fast Castle, the Farne Islands, Donna Nook and Blakeney Point.

Location	**2004 pup production**	**Overall annual change in pup production**		
		1990-1994	1995-1999	2000-2004
Inner Hebrides	3,385	+8.06	-1.88	+2.11
Outer Hebrides	12,319	+5.43	-2.12	-1.42
Orkney	19,123	+13.46	+5.93	+0.81
Isle of May + Fast Castle	2,612	+5.17	+12.45	+2.22
Farne Islands	1,133	+1.68	-2.63	-0.51
Donna Nook + Blakeney Point	1078	+12.98	+12.38	+14.29
North Sea (i.e. previous 3 locations)	4,823	+4.46	+7.39	+3.53
Total	**39,650**	**+8.46**	**+2.24**	**+1.78**

Table 3. Pup production estimates for breeding colonies surveyed less regularly

Location	**Date and location of last survey**	**Pup production**
Mainland Scotland*	Helmsdale (Duncansby Head to Helmsdale, 2003	947 (one count)
	**Loch Eriboll, Eilean nan Ron (Tongue) 2004	817 (modeled, 3 counts)
Other colonies	Various, from Table 5	822
Shetland	2004	943
South-west Britain	South-west England	1,750
	Wales 1994	
Total		**5,279**

*South Ronaldsay has been included with the main Orkney breeding colonies.

**Loch Eriboll and Eilean nan Ron are aerially surveyed annually and production estimates obtained using the same modeling process as the main breeding colonies.

Table 4. Estimates of pup production for colonies in the Inner and Outer Hebrides, Orkney and the North Sea, 1960-2004.

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 4 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
1997	3076	11946	14051	3698	32771
1998	3087	12434[2]	16367[1]	3989	35877
1999	2787	11759[2]	15462[1]	3380	33388
2000	3223	13396	16281[1]	4303	37210
2001	3032	12427[2]	17938[1]	4134	37531
2002	3096	11248[2]	17942[1]	4418	36714
2003	3386	12741[2]	18652[1]	4657	39436
2004	3385	12319	19123[3]	4823	39650

[1] ***Production estimates for North Flotta, South Westray, Sule Skerry and South Ronaldsay included in the Orkney total for the first time.***
[2] Production estimates for Mingulay, Berneray and Fiaray (latter two off Barra) included in the Outer Hebrides total for the first time.
[3] Blakeney Point included with Donna Nook for the first time.

Table 5. Scottish grey seal breeding sites that are not surveyed annually and/or have recently been included in the survey programme. Data from 2004 are in bold type.

	Location	**Survey method**	**Last surveyed, frequency**	**Number of pups**
Inner Hebrides	Loch Tarbert, Jura	SMRU visual	2003, every 3-4 years	10
	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, every 2-3 years	22
	Muck	SMRU photo	1998, every other year	36
	Rum	SNH ground	2003, annual	10-15
	Canna	SMRU photo	2002, every other year	54
	Rona	SMRU visual	1989, infrequent	None seen
	Ascrib Islands, Skye	SMRU photo	2002, every other year	60
	Heisgeir, Dubh Artach, Skerryvore	SMRU visual	1995, every other year 1989, infrequent	None None
Outer Hebrides	Barra Islands Fiaray & Berneray	SMRU photo	annual	Included with Outer Hebrides
	Sound of Harris islands	SMRU photo	2002, every 2-3 years	358
	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	50, 58
	Islands close to Handa	SMRU visual	2002	10
	Faraid Head	SMRU visual	1989, infrequent	None seen
	Eilean Hoan, Loch Eriboll	SMRU visual	1998, annual	None
	Rabbit Island, Tongue	SMRU visual	2002, every other year	None seen
Orkney	Sule Skerry	SMRU photo	1998 - 2002	Included with Orkney
	Sanday, Point of Spurness	SMRU photo	1999, 2002, 2004	62, 10, **27**
	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
	Rothiesholm, Sronsay	SMRU photo	2004	**61**
	Eday mainland	SMRU photo	2000, 2002	8, 2
Others	Firth of Forth islands, Inchcolm; Craigleith (by North Berwick)	SMRU photo, Forth Seabird Group	Infrequent, 1997 2003, 2004	<10, 4 86, **72**
Total				**822**

Table 6 Pup production estimates and maximum pup counts for grey seal colonies in Shetland.

Location in Shetland	**Estimated production**		**Maximum count**
	50% moulter classification	90% moulter classification	
Papa Stour	174	196	
Dale of Walls	60	66	
Muckle Roe	20	23	
Rona's Voe	99	106	
Mousa	110	140	
Fetlar	51	50	
Modeled total	**513**	**582**	
Whalsey Islands			102
South Havra			4
Fitful Head			18
Uyea (North Mainland)			238
Total max counts			**362**
Minimum production	**876**	**943**	

Figure 1


Grey seal breeding colonies
in Britain
Colonies asterisked have been
put forward as potential Special Areas of Conservation
Shetland
*Faray & Holm of Faray
*North Rona
Orkney
Loch Eriboll
Outer
Hebrides
Helmsdale & Berriedale
*Monach
Isles
Major colony
Minor colony
*Treshnish Isles
Inner
Hebrides
*Isle of May
St Abbs Head
Farne Islands
Donna Nook
*North Pembroke
Coast
*Ramsey
*Skomer
Lundy
Isles of Scilly

Figure 2a. Total estimated pup production, with 95% confidence limits, for all the major, annually monitored colonies in Scotland and England from 1984 to 2004.

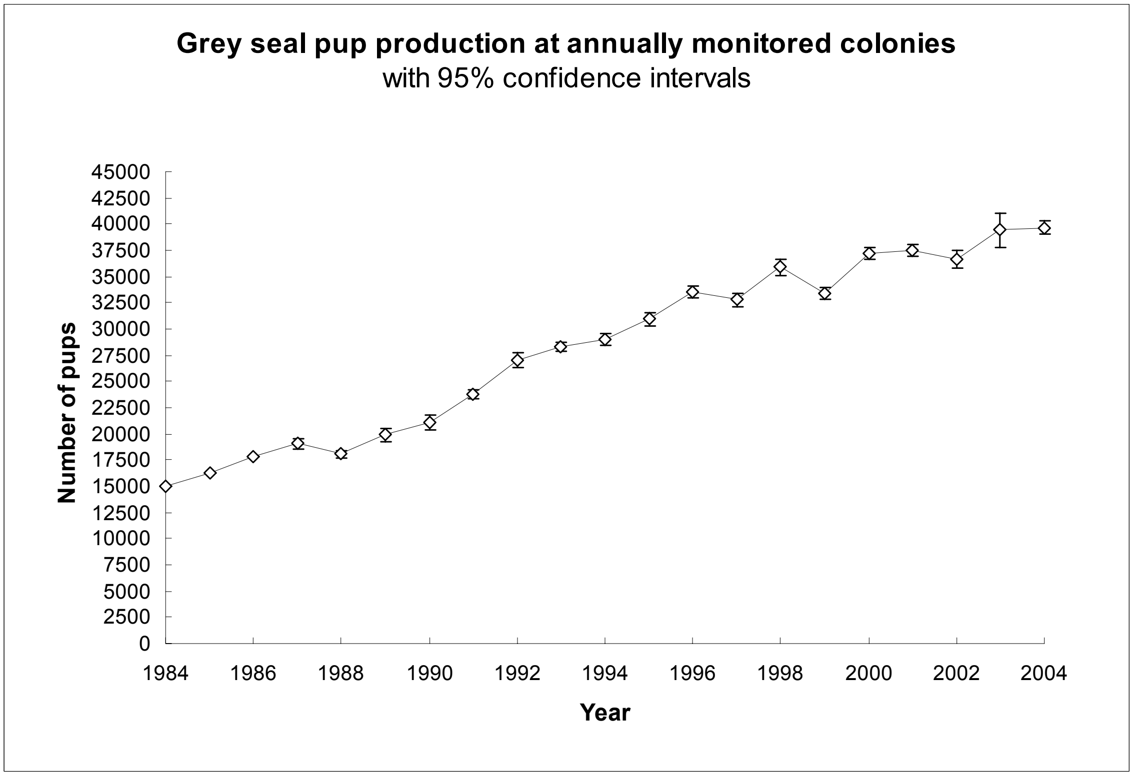


Figure 2b. Grey seal pup production trajectories from 1960 to 2004.

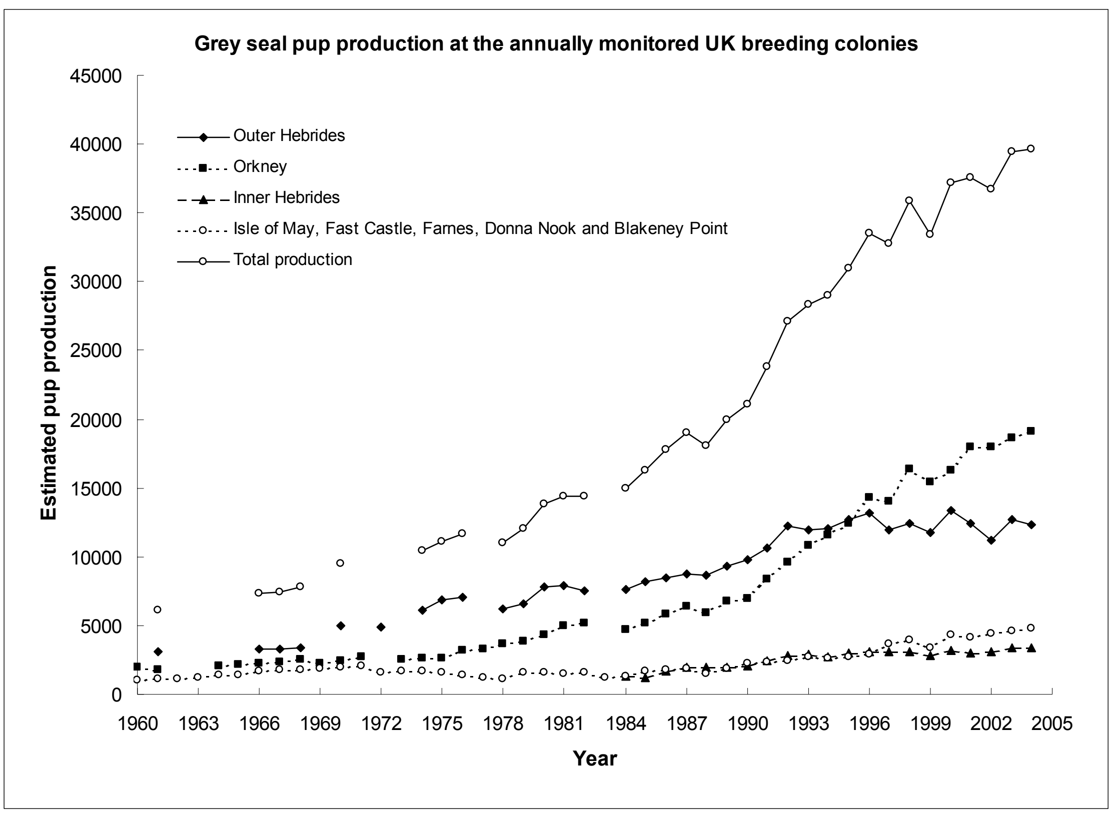
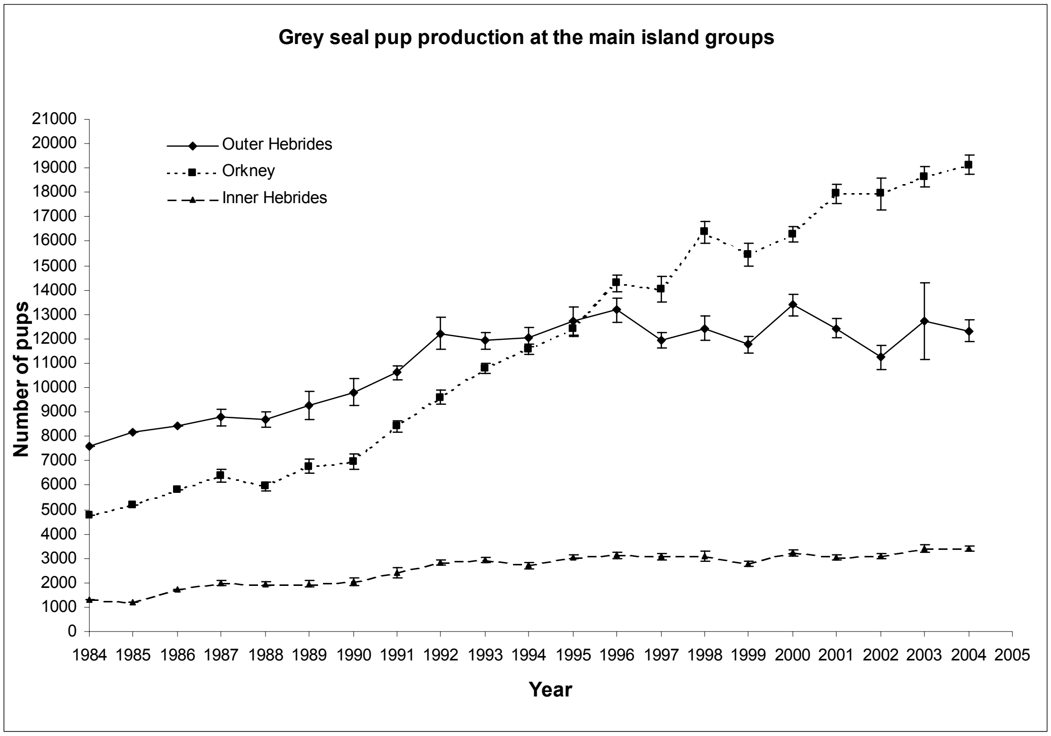
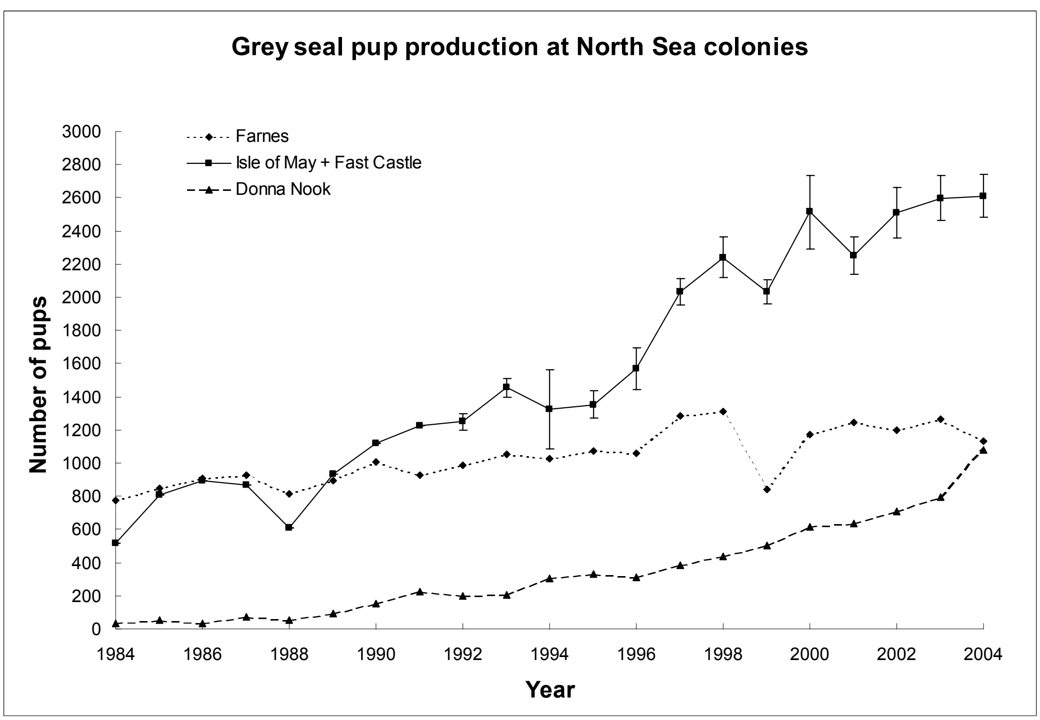


Figure 3. Trends in pup production at the major grey seal breeding colonies since 1984. Production values are shown with their 95% confidence limits where these are available. These limits assume that the various pup development parameters involved in the estimation procedure remain constant from year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

3a) Outer Hebrides, Orkney and Inner Hebrides



3b) Farne Islands, Isle of May and Donna Nook



Len Thomas and John Harwood

Estimating the size of the UK grey seal population between 1984 and 2004: model selection, survey effort and sensitivity to priors.

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

Summary

We used a Bayesian state space modelling framework to fit and compare models of British grey seal population dynamics using regional estimates of pup production from 1984 to 2004. The models allow for a number of different forms of density dependence in either pup survival or fecundity, as well as fitness-dependent movement of recruiting females between regions. There was little difference between models in the adjusted posterior log-likelihoods, meaning that none of the models was obviously best at describing the data. However, this could be a result of the fitting methods used. The estimated adult population size in 2004 varied from 105,000 (95% CI 78-141,000) for the simplest density-dependent survival model to 234,000 (95% CI 167-344,000) for the simplest density-dependent fecundity model, the other models having intermediate estimates.

The estimates of adult survival and pup production at carrying capacity were relatively insensitive to the prior distributions that we chose. However, estimates of juvenile survival, fecundity and movement were almost completely determined by their priors.

Reducing the frequency of pup production estimates to one every second year had little effect on the posterior mean estimates of population size and model parameters, but the variance of the estimates of population size increased as did the sensitivity of the parameters to their prior distributions.

Including a fabricated independent estimate of population size in 2004 for each region enhanced our ability to distinguish between the models. We discuss how such an actual estimate of this variable might be obtained.

Introduction

In this paper, we expand on the methodology that has been used to estimate the size of the grey seal population associated with those UK colonies that are surveyed each year by SMRU (Thomas and Harwood 2003, 2004). The underlying models are formulated in a state-space framework (Buckland *et al.* 2004, Thomas *et al.* 2005, Newman *et al.* in press). A state-space model is composed of a state process, which models the true but unknown state of the population (i.e., the number of animals in each age group and region in each time period), and an observation process, which models how the survey data are generated given the true states.

Previous versions of this model have used a simple Beverton-Holt function to describe the relationship between pup survival or fecundity and population size. This function predicts that most of the changes in these parameters occur at population sizes well below carrying capacity, whereas the conventional wisdom is that, for large vertebrates, these changes are unlikely to occur until the population is close to its carrying capacity. To capture this we used an extended version of the Beverton-Holt function, first suggested by Shepherd (1982), which has similar properties to the generalised logistic function. We refer to this as "extended density dependence".

We used an analytic approach to investigate the sensitivity of the posterior parameter estimates to the priors that we used, and we examined the effects of reduced survey effort by removing every other year of data from the time series we analysed..

Materials and Methods

Models

We compared models that incorporate density dependent pup survival (DDS) with models incorporating density dependent fecundity (DDF). The basic DDS model is identical to that presented previously (Thomas and Harwood 2003, 2004), while the basic DDF model is a slight modification of that presented by Thomas and Harwood (2004). Both basic models were also extended (EDDS and EDDF) to include an extra parameter governing the relationship between density dependence and population size.

In constructing the state processes, we divide the seal population in each region into 7 age classes: pups (age 0), age 1 – age 5 adult females (pre-breeding), and age 6 and older females. Note that our models do not include adult males.

The time step for the process models is 1 year, beginning just after the breeding season. The models are made up of four sub-processes: survival, age incrementation, movement of recruiting females and breeding.

Survival is modelled as a binomial random process. For the DDS model, we assume that pup survival follows a Beverton-Holt function of the form:

$$\phi_{p,r,t} = \frac{\phi_{p\max}}{1+\beta_r n_{0,r,t-1}}$$

where $n_{0,r,t-1}$ is the number of pups born in region r in year t-1, $\phi_{p,r,t}$ is survival rate of these pups, $\phi_{p\max}$ is maximum pup survival rate, and $1/\beta_r$ is proportional to the carrying capacity of the region. The EDDS model includes an extra parameter, ρ, that can alter the shape of the relationship between pup survival and pup numbers:

$$\phi_{p,r,t} = \frac{\phi_{p\max}}{1+\left(\beta_r n_{0,r,t-1}\right)^{\rho}} \qquad (1)$$

Figure 1 shows the effect of different levels of ρ. For the DDF and EDDF models, we assume pup survival is constant across regions and times, i.e., $\phi_{p,r,t} = \phi_p$.

Since half of the pups born will be male, the expected number of female pups surviving in both models will be $0.5\,\phi_{p,r,t} n_{0,r,t-1}$. For all models, we assume that adult female survival rate, ϕ_a is constant across regions and time.

Age incrementation is deterministic – all seals age by one year (although those in the age 6+ category remain there).

To model movement, we assume that only females breeding for the first time may move from their natal region. Once a female has started breeding she remains faithful to that region. We assume that movement is fitness dependent (Ruxton and Rohani 1998), such that females will only move if the value of the density dependent parameter (pup survival or fecundity) is higher elsewhere, and the probability of movement is proportional to the difference in the density dependent parameter between regions. In addition, we assume that females are more likely to move among regions that are close together, and that females show some degree of site fidelity – that is, they may not move even if conditions for their offspring will be better elsewhere. We model movement from each region as a multinomial random variable where probability of movement from region r to region i at time t is:

$$\rho_{r\to i,t} = \begin{cases} \dfrac{\theta_{r\to i,t}}{\sum_{j=1}^{4}\theta_{j\to i,t}} & : \sum_{j=1}^{4}\theta_{j\to i,t} > 0 \\ I_{i=r} & : \sum_{j=1}^{4}\theta_{j\to i,t} = 0 \end{cases}$$

where $I_{i=r}$ is an indicator that is 1 when i=r and 0 otherwise, and

$$\theta_{r\to i,t} = \begin{cases} \gamma_{sf} & : i = r \\ \dfrac{\gamma_{dd}\max\left(\Delta_{i,r,t},0\right)}{\exp\left(\gamma_{dist} d_{r,i}\right)} & : i \neq r \end{cases}$$

where γ_{sf}, γ_{dd}, and γ_{dist} are three movement parameters that index the strength of the site fidelity, density dependence and distance effects respectively, $\Delta_{i,r,t}$ is the difference in the density dependent parameter between regions i and r (see below), and $d_{r,i}$ is the 20% trimmed mean of the distances between colonies in regions r and those in region i (standardized so that the largest distance is 1.0). For the DDS and EDDS models,

$$\Delta_{i,r,t} = \phi_{p,i,t} - \phi_{p,r,t}$$

while for the DDF and EDDF models,

$$\Delta_{i,r,t} = \alpha_{i,t} - \alpha_{r,t}$$

where $\alpha_{r,t}$ is the fecundity rate in region r at time t, as defined below.

We model breeding by assuming that the number of pups produced is a binomial random variable, with rate $\alpha_{r,t}$. For the DDS and EDDS models, we assume this value is constant across regions and times, i.e., $\alpha_{r,t} = \alpha$. For the DDF model, we assume this value follows a Beverton-Holt function of the form:

$$\alpha_{r,t} = \frac{\alpha_{\max}}{1+\beta_r n_{6+,r,t}}$$

This implies that the probability of a female breeding in a particular year is influenced by the number of age 6+ females in that year. Note that this is slightly different from the DDF model of Thomas and Harwood (2004), in which fecundity was a function of the number of pups in the previous breeding season. This resulted in increasing oscillations in pup production under some parameter combinations (there is some evidence of this in the upper confidence limit for the DDF model in Figure 2 of that paper). A viable alternative would be to model breeding probability as a function of the number of age 6+ females in the previous year. The EDDF model is similar, with

$$\alpha_{r,t} = \frac{\alpha_{\max}}{1+\left(\beta_r n_{6+,r,t}\right)^{\rho}} \qquad (2)$$

For the observation process, we assume that pup production estimates follow a normal distribution with a constant coefficient of variation (CV) which we assume to be a known value. In the runs reported here, we fixed this CV at 25%.

In summary, the DDS and DDF models have 10 parameters. They share 8: adult survival ϕ_a, one carrying capacity parameter-related parameter for each region β_1 - β_4, and three movement parameters γ_{sf}, γ_{dd}, and γ_{dist}. They differ in two parameters: the DDS model has maximum pup survival $\phi_{p\max}$ and constant fecundity α, while the DDF model has constant pup survival ϕ_p and maximum fecundity $\alpha_{\max}$. The EDDS and EDDF models have one additional parameter, ρ, for the shape of the density-dependent response.

Data and Priors

Our input data were the pup production estimates for 1984-2004 from Duck and Mackey (2005), aggregated into regions. Unlike last year, we did not include the Helmsdale colony in the North Sea region as it was not surveyed in 2004, so our totals for the North Sea are slightly lower than those used last year.

In previous years, we have used independent prior distributions on each parameter, but the introduction of the ρ parameter makes this inadvisable. Carrying capacity is strongly affected by ρ (Figure 1), so a prior on the carrying capacity parameters β that would be reasonable at one level of ρ would be unfeasible at a different ρ. Hence, instead of setting priors on the β s independently of the values of the other parameters, we used a re-parameterization to set priors on the numbers of pups at carrying capacity in each region and then generated values for the β s conditional on the realized values of ρ and the other model parameters. We denote the number of pups at carrying capacity in region *r* as χ_r. For the EDDS model, it can be shown that

$$\beta_r = \frac{1}{\chi_r}\left[\frac{0.5\alpha\phi_{p\max}\phi_a^5}{1-\phi_a}-1\right]^{1/\rho} \qquad (3)$$

(values of β_r <0 are set to 0). Similarly, for the EDDF model,

$$\beta_r = \frac{\left[\alpha_{\max}\tau - 1\right]^{1/\rho}}{\chi_r \tau}$$

where $\tau = 0.5\phi_p\phi_a^5 / \left(1-\phi_a\right)$. For the DDS and DDF models, the formulae are the same, except that $\rho = 1$.

Prior distributions for each parameter are given in Table 1, and are shown on Figures 3 and 5.

Table 1. Prior parameter distributions

Param	Distribution	Mean	Stdev
ϕ_a	Be(22.05,1.15)	0.95	0.04
$\phi_{p\max}$, ϕ_p	Be(14.53,6.23)	0.7	0.1
χ_1	Ga(4,2500)	10000	5000
χ_2	Ga(4,1250)	5000	2500
χ_3	Ga(4,3750)	15000	7500
χ_4	Ga(4,10000)	40000	20000
ρ	Ga(4,2.5)	10	5
γ_{sf}	Ga(2.25,1.33)	0.5	0.33
γ_{dd}	Ga(2.25,0.49)	3	2
γ_{dist}	Ga(2.25,0.22)	ln(3)	ln(2)
α, $\alpha_{\max}$	Be(22.05,1.15)	0.95	0.04

Prior distributions for the states in the DDS and EDDS models were generated using the priors for the parameters in conjunction with the 1984 data, as described by Thomas *et al.* (2005). Prior states for the DDF and EDDF model were generated in a similar manner, except that the number of age 6+ females was sampled from a Poisson distribution, with mean equal to the solution of the equation

$$n_{0,r,0} = \frac{\alpha_{\max}}{1+\left(\beta_r n_{6+,r,0}\right)^{\rho}} n_{6+,r,0}$$

for $n_{6+,r,0}$ given the other values. This can lead to unfeasibly large or small values for the mean, so values were bounded by $n_{0,r,0}$ as a lower bound and $n_{5,r,0}\,\phi_a/(1-\phi_a)$ as an upper bound.

Fitting Method

We used the same particle filtering algorithm as described in Thomas and Harwood (2004), although the algorithm has now been ported from SPlus to C, enabling far larger runs to be undertaken. Particle filtering (also called sequential importance sampling or SIS) is a computer-intensive method for estimating the posterior distribution of the parameters and states of a state-space model. It is well suited to the analysis of time series data, as data points are introduced one year at a time into the algorithm, making it potentially more efficient than other computer-intensive techniques such as Markov chain Monte Carlo (MCMC). Particle filtering methods were first developed for engineering applications and have only recently been applied to biological problems. Consequently, much methodological work is still required. An introduction to particle filtering algorithms in the context of wildlife studies is given by Newman *et al.* (in press), and a detailed description of a similar algorithm to the one used here, applied to a similar model of seals, is given by Thomas *et al.* (2005). The differences between the algorithm of Thomas *et al.* (2005) and the one used here are outlined by Thomas and Harwood (2004).

Model outputs and comparison

The output from a particle filter is a set of weighted samples (particles) taken from the prior distributions on the parameters and states and projected forward stochastically through the time series. The weights relate to the manner in which the particles were sampled, how they were projected forward and the likelihood of the observed pup production given the simulated pup numbers. We can use these particles to estimate quantities of interest such as posterior means or credibility (confidence) intervals on parameters and states. One issue that arises is the accuracy of the estimates, in terms of Monte-Carlo error. We can calculate the effective sample size of the particles as

$$\mathrm{ESS} = \frac{K}{1+\left[\mathrm{CV}(w)\right]^2}$$

where K is the number of particles and CV(w) is the coefficient of variation of the weights of these particles. Our aim was to simulate enough particles to achieve an ESS of at least 1000, although that was not possible for some models in the time available. We report ESS achieved in the Results section.

For all four models, we present posterior estimates of the model parameters and estimated pup production from 1984-2004. The models also estimate adult female numbers, but do not include adult males. We therefore calculated total pre-breeding population sizes by assuming that the number of adult males is 73% of the number of adult females (Hiby and Duck, unpublished).

To compare the models, we calculated the mean posterior Akaike Information Criterion (MPAIC) using the same method as Thomas and Harwood (2003, 2004). This criterion is a form of penalized likelihood, which recognizes the fact that models with more parameters are expected to fit better *a priori* by adding a penalty proportional to the number of model parameters. It is similar in spirit to the Bayesian Deviance Information Criterion (Spiegelhalter et al. 2002). Models were compared using Akaike weights (Burnham and Anderson 1998, p124), which can be thought of in the Bayesian context as the posterior probability of each model being the best approximating model.

Sensitivity to priors

Since we used informative prior distributions on the parameters, it is of interest to determine how sensitive our results are to the choice of prior. We used the methods developed by Millar (2004) and implemented by Newman (2005, pers. comm..) to determine local sensitivity – that is sensitivity of results to changes in the hyperparameters of the prior distributions (as opposed to changes in the choice of distribution, for example). Specifically, we estimated the sensitivity of the posterior mean of each parameter with respect to changes in the two hyperparameters that specify the prior, by estimating

$$\frac{dE[\theta \mid y]/da_i}{dE[\theta]/da_i}$$

from the sample of particles, where $E[\theta \mid y]$ is the posterior expected value of the parameter (i.e., the expected value given the data y), $E[\theta]$ is the prior value of the parameter, a_i is the value of hyperparameter i (i = 1, 2), and dx/dy indicates the first differential of x with respect to y. Despite the complex-seeming formulation, the output has a nice interpretation: it is a measure of the relative contribution to the posterior coming from the data and prior (see Results) .

Effect of reduced survey effort
We investigated the effect of reducing the frequency of pup production estimates by re-fitting using only every second year of data. Since our fitting algorithm makes use of the first year of data to set priors on the states, and the second year to implement an efficiency-enhancing method called rejection control (Thomas and Harwood 2004), we retained both 1984 and 1985 data, the first "missing" data point being 1986.

Effect of an independent estimate of adult population size
We investigated the effect of obtaining an independent estimate of the adult population size on our ability to distinguish between the models by re-calculating the particle weights for each model, after including one additional piece of data: regional estimates of adult female population size in 2004 (which we assumed to have a CV of 25%). The value we used for these "fabricated" data was the posterior mean estimates of adult population size from the DDF model (which was the model with the lowest posterior AIC value – see Results). Based on these additional data, we re-calculated the particle weights, and then the posterior AIC and Akiake weights.

Results

Effective sample size (ESS)
For some models, an extremely large number of particles were required to achieve a unit increase in ESS (Table 2). The worst was the EDDF model where $222.2\text{x}10^4$ particles were required for each unit of ESS. Hence we did not achieve our target of ESS ≥ 1000 for all models (Table 2). Nevertheless, the Monte-Carlo error in our results is likely to be small. For example, dividing the particles from the EDDF model into two, estimated mean adult population size in 1984 is $64.3\text{x}10^4$ from the first half and $64.2\text{x}10^4$ from the second.

Table 2. Number of particles (K) and effective sample size (ESS) for the results presented here. Note that number of particles is before rejection control, ESS is afterwards (see Thomas and Harwood 2004 for details).

Model	K ($\text{x}10^6$)	ESS	ESS/K ($\text{x}10^4$)
All data			
DDS	60	795	7.5
EDDS	424	514	82.4
DDF	160	1034	15.4
EDDF	614	276	222.4
Alternate years removed			
DDS	60	12103	0.5
EDDS	60	2230	2.6
DDF	60	8275	0.7
EDDF	32	906	3.5

Comparison of models for density dependence
Smoothed posterior estimates of pup production (Thomas *et al.* 2005) for the four models are shown in Figure 2. The estimates are very similar, and there is little difference in posterior likelihood or AIC between the models (Table 2). The model with the minimum AIC is the DDF model, but the next best model (EDDS) has a mean posterior AIC only 1.57 higher. All four models are within 3 AIC points of one another.

Subjectively, the extended density dependence models appear to do a better job of capturing the recent levelling-off of pup production in the Inner and Outer Hebrides. However none of the models' estimates can reproduce the rapid increase in pup production in the Hebrides and Orkney in the early 1990s.

Although the models produce similar estimates of pup production, they give substantially different estimates of total predicted population size (Table 3 and Appendix 1). The DDF model estimates that there are 2.25 times as many seals as the DDS model, with the other two falling in between.

Table 2. Mean posterior log-likelihood, AIC and Akaike weights for models fit to data from 1984-2004.

Model	LnL	AIC	ΔAIC	Akaike weight
DDS	-685.08	1390.16	1.91	0.19
EDDS	-683.91	1389.82	1.57	0.22
DDF	-684.12	1388.25	0.00	0.48
EDDF	-684.59	1391.20	2.95	0.11

Table 3. Estimated size, in thousands, of the British grey seal population at the start of the 2004 breeding season, derived from models fit to data from 1984-2004. Numbers are posterior means with 95% credibility intervals in brackets.

	DDS	EDDS
North sea	11.6 (8.9-15.8)	17.0 (9.5-24.8)
Inner Hebrides	8.9 (6.8-11.6)	10.6 (6.8-14.5)
Outer Hebrides	32.7 (24.0-44.2)	41.8 (27.0-57.4)
Orkney	51.5 (38.6-69.8)	74.5 (45.7-94.4)
Total	104.7 (78.3-141.4)	143.5 (89.0-191.1)
	DDF	EDDF
North sea	25.3 (18.5-36.1)	20.4 (15.6-26.6)
Inner Hebrides	21.4 (15.1-32.3)	14.6 (11.3-20.0)
Outer Hebrides	84.9 (58.7-131.5)	57.5 (43.9-77.3)
Orkney	102.5 (75.3-144.4)	78.7 (61.8-101.5)
Total	234.1 (167.6-344.2)	171.1 (132.5-225.4)

Posterior parameter estimates for the models are given in Figure 3. For the DDS and DDF models, the posterior mean adult survival (ϕ_a) is similar to the prior of 0.95 (although the variance is much reduced), but it is substantially lower in the extended density dependence models (0.91 in EDDS and 0.90 in EDDF). The juvenile survival and fecundity parameters (ϕ_j and α) are almost unchanged relative to the prior in all four models. Similarly, the movement parameters (γ s) are also little changed, except for the density dependence parameter γ_{dd} , which has a posterior mean that is half the prior mean in the DDS and DDF models. Posterior distributions of the carrying capacity parameters (χ s) are somewhat tighter than the priors, with posterior mean estimates that vary between models. In the extended density dependence models, the posterior for ρ has lower mean and variance than the prior – in particular for the EDDF model, where the prior mean of 10 is outside the 95% credibility interval of the posterior.

Sensitivity to priors

Results for the four models are shown in Table 4. The sensitivity values can be interpreted as a measure of the relative contribution to the posterior coming from the data and the prior: low values mean there is a strong influence of the data while high values mean there is a strong influence of the prior. Millar (2004) has suggested a quantitative interpretation of these sensitivities: for example the value of 0.15 for hyperparameter 1 of ϕ_a in the DDS model means that the posterior mean of ϕ_a is influenced 15% by the prior value of this hyperparameter (which is 22.05) and 85% by the data. However, it is unclear how sensitivities of greater than 1 can be interpreted in this way.

Table 4. Sensitivity of the posterior mean of each parameter to changes in the two hyperparameters that specify the prior on that parameter, under four models of British grey seal population dynamics fit to pup production data from 1984-2004.

	1	2	1	2
	DDS		EDDS	
ϕ_a	0.15	0.16	0.23	0.19
$\phi_{p\max}, \phi_p$	0.73	0.81	1.31	1.06
χ_1	0.19	0.21	0.62	0.61
χ_2	0.16	0.22	0.15	0.13
χ_3	0.27	0.42	0.18	0.20
χ_4	0.32	0.47	0.75	0.94
ρ	-	-	0.66	0.42
γ_{sf}	0.86	1.25	1.05	1.29
γ_{dd}	0.68	0.34	1.14	0.92
γ_{dist}	1.21	1.67	1.26	1.84
$\alpha, \alpha_{\max}$	0.83	0.95	1.26	1.07
	DDF		EDDF	
ϕ_a	0.25	0.31	0.13	0.08
$\phi_{p\max}, \phi_p$	1.07	0.98	1.04	0.94
χ_1	0.19	0.16	0.64	0.63
χ_2	0.14	0.16	0.23	0.18
χ_3	0.21	0.29	0.30	0.30
χ_4	0.49	0.57	0.70	0.84
ρ	-	-	0.43	0.21
γ_{sf}	0.83	1.28	0.92	0.92
γ_{dd}	0.60	0.28	1.03	0.91
γ_{dist}	1.27	1.84	1.04	1.24
$\alpha, \alpha_{\max}$	1.22	1.09	0.98	1.02

In general, the sensitivity values confirm the impressions gained from the plots of prior and posterior distributions (Figure 3): ϕ_a has low sensitivity, ρ has reasonably low sensitivity (particularly for the EDDF model), the χ s have moderate sensitivity except for some parameters in some models (e.g., χ_4 in the EDDS and EDDF modes), and the other parameters have high sensitivity. The ϕ_j and α parameters are almost completely determined by their prior, as are the movement parameters, except for γ_{dd} in the DDS and DDF models.

Effect of reduced survey effort

Fitting the models with approximately half the data had relatively little effect on either the estimates of true pup production (Figure 4) or parameters (Figure 5), although the estimates of pup production had wider credibility intervals, particularly at the beginning and end of the time series, and the parameter estimates were generally closer to their prior distributions.

DDF still had the lowest AIC, with the difference between that and the other models (especially EDDF) being slightly greater (Table 5). The predicted total population sizes for 2004 (Table 6) were broadly similar to the estimates using the entire dataset (Table 3), but note that the values in Table 6 are predictions, not estimates, because the 2004 data were excluded. However, the posterior credibility intervals were noticeably wider.

Table 5. Mean posterior log-likelihood, AIC and Akaike weights for models fit to data from1984, 1985, 1987, 1989, 1991, 1993, 1995, 1997, 1999, 2001 and 2003.

Model	LnL	AIC	ΔAIC	Akaike weight
DDS	-356.43	732.87	1.63	0.24
EDDS	-355.84	733.68	2.44	0.16
DDF	-355.62	731.24	0.00	0.55
EDDF	-357.28	736.56	5.32	0.04

Sensitivities of the parameters were almost all greater (Table 7), indicating a stronger influence of the prior as would be expected with less data. For example, in the EDDS model, sensitivity of the two hyperparameters for the gamma prior on ρ was 0.66 and 0.42 with the full dataset, but 0.95 and 0.69 with the reduced dataset. The posterior mean estimate of this parameter was 6.24 with the whole dataset, but 7.23 with the reduced dataset – closer to the prior mean of 10.

Table 6. Predicted size, in thousands, of the British grey seal population at the start of the 2004 breeding season, derived from models fit to a subset of the data from 1984-2003 (see Table 5 legend). Numbers are posterior means with 95% credibility intervals in brackets.

	DDS	EDDS
North sea	11.0 (8.0-15.5)	17.5 (8.7-27.3)
Inner Hebrides	8.8 (6.4-12.1)	11.4 (6.9-18.0)
Outer Hebrides	31.8 (21.6-45.1)	45.0 (26.8-69.7)
Orkney	49.3 (35.0-69.1)	72.6 (40.2-99.8)
Total	101 (71.1-141.8)	146.6 (82.6-214.8)
	DDF	EDDF
North sea	25.3 (17.2-38.6)	19.8 (14.3-28.8)
Inner Hebrides	21.7 (14.4-34.1)	15.6 (11.0-22.7)
Outer Hebrides	82.5 (54.2-140.2)	62.3 (43.4-88.0)
Orkney	104.7 (71.1-157.3)	74.3 (55.4-102.6)
Total	237.2 (156.9-370.2)	172.1 (124.0-242.1)

Effect of an independent estimate of adult population size

Including an independent estimate of adult population size created a clear distinction between the models (Table 8), with the DDF model having 96% of the posterior Akiake weight, and the EDDF model (which had the closest adult population size estimates to the DDF model) having the remaining 4%.

Discussion

For the runs reported here, we fixed the CV of the pup production estimates at 25%. This value is higher than the only available estimate (Hiby and Duck, unpublished) of 7% for individual colonies. The effect of using a higher CV is to reduce the influence of the data on the posterior states and parameters, relative to the priors. We therefore regard our results as preliminary, especially those regarding the sensitivity of the parameters to the priors and the comparison of models.

Table 7. Sensitivity of the posterior mean of each parameter to changes in the two hyperparameters that specify the prior on that parameter, under four models of British grey seal population dynamics fit to a subset of the data from 1984-2003 (see Table 5 legend).

	1	2	1	2
	DDS		EDDS	
ϕ_a	0.18	0.19	0.28	0.24
$\phi_{p\max}, \phi_p$	0.77	0.85	1.26	1.04
χ_1	0.20	0.20	0.71	0.71
χ_2	0.22	0.31	0.25	0.25
χ_3	0.35	0.54	0.29	0.37
χ_4	0.37	0.49	0.77	0.93
ρ	-	-	0.95	0.69
γ_{sf}	0.90	1.25	1.00	1.14
γ_{dd}	0.74	0.48	1.01	0.88
γ_{dist}	1.20	1.51	1.21	1.44
$\alpha, \alpha_{\max}$	0.84	0.91	1.21	1.06
	DDF		EDDF	
ϕ_a	0.29	0.36	0.14	0.09
$\phi_{p\max}, \phi_p$	1.15	1.01	1.15	1.02
χ_1	0.22	0.18	0.89	0.91
χ_2	0.19	0.21	0.58	0.57
χ_3	0.26	0.37	0.50	0.56
χ_4	0.50	0.55	0.79	0.89
ρ	-	-	1.19	0.89
γ_{sf}	0.87	1.24	1.03	1.04
γ_{dd}	0.72	0.42	1.06	1.02
γ_{dist}	1.25	1.64	1.14	1.27
$\alpha, \alpha_{\max}$	1.29	1.12	1.15	1.04

Table 8. Mean posterior log-likelihood, AIC and Akaike weights for models fit to pup production data from 1984-2004 and fabricated regional estimates of adult female population size in 2004.

Model	LnL	AIC	ΔAIC	Akaike weight
DDS	-690.57	1401.14	12.86	0.00
EDDS	-691.40	1404.80	16.52	0.00
DDF	-684.14	1388.28	0.00	0.96
EDDF	-686.40	1394.80	6.52	0.04

We are actively working on improving the fitting methods. The current algorithm is simple (and therefore reliable) but inefficient. We expect to be able to improve efficiency, while at the same time maintaining reliability, using tools such as auxiliary particle filtering, simulated annealing and tempering, and limited kernel smoothing (Doucet *et al.* 2001, Lui 2001, Thomas *et al.* 2005, Newman *et al.* in press). We are also working with K. Newman, C. Fernandez and S. Buckland on a comparison of MCMC and particle filtering for a model similar to the DDS one (Newman et al. in prep). Preliminary results indicate that judicious application of tools such as kernel smoothing can result in large gains in efficiency with little bias and that, in cases like this where there is relatively little information in the data relative to the priors, for some parameters, particle filtering appears to be more efficient than MCMC.

Our results from the DDS model are comparable with those of Thomas and Harwood (2004), although the estimated total population sizes presented here are slightly higher for comparable years. The difference is explained by the change in prior on the density dependence parameters. The priors on the β parameters used by Thomas and Harwood (2004) translate into expected numbers of pups at carrying capacity of 5000, 3500, 14000 and 18000 for the North Sea, Inner Hebrides, Outer Hebrides and Orkneys respectively. Here we used priors with higher means (the χ parameters, Table 1: 10000, 5000, 15000, 40000) because they seemed better justified. In both cases, the prior distributions had large variances (coefficient of variation of 50%) and the sensitivity of the posteriors to the prior values was not high – especially for the DDS model (Table 4) – so even a large change in the prior had only a small effect on the estimated adult population size.

Our estimated total population sizes from the DDF model are substantially lower than those of Thomas and Harwood (2004), and much more plausible. Thomas and Harwood noted a problem with oscillations in estimated pup production under their DDF model, and we have rectified that by making fecundity dependent on current 6+ female numbers rather than the previous years pup production. The change appears also to have caused our estimates of population size to decrease.

The estimates of total population size from the new extended density dependence models are intermediate between the DDF and DDS models. Although our model selection criterion did not indicate that they provide a more parsimonious fit than the simple density dependence models after taking the additional parameter into account, the pup production trajectories correspond more closely to our biological understanding of the system. The extended models may prove superior if a lower CV is used for the observation process

None of the models we have used to date have provided an adequate fit to the rapid increase in pup production in the Inner and Outer Hebrides (and, to a lesser extent, in Orkney) observed in the early 1990s . A rapid increase in one region could be a consequence of density dependent movement, but a rapid increase in three out of four cannot. It may be fruitful to investigate the use of covariates such as food supply or climatic conditions that may influence fecundity or juvenile survival in a time-dependent manner. An EPSRC-funded PhD student will be investigating this over the next 3 years.

Our analysis of prior sensitivity has been useful in supplementing the impressions gained by comparing prior and posterior parameter plots. This work can be extended in two ways. Firstly, it would be more useful to estimate the sensitivity of the posterior parameter mean to variation in the prior mean (and its variance) rather than looking at sensitivity with respect to variation in the prior hyperparameters. Secondly, an important output of our modelling is the total population size estimate, and it would be useful to estimate sensitivity of this estimate to variation in the priors on the parameters. We plan to do both of these.

We found little evidence in the pup production estimates to support one model over another, although we acknowledge that this may be a result of the high CV used in the observation model. Introducing a single estimate of adult population size was enough to enable us to unambiguously distinguish between the models. Clearly, a more comprehensive assessment will be required, but there may be merit in reducing the frequency of the pup production surveys in order to finance a new survey designed to estimate total population size.

A total population survey would not be easy to achieve, but one possibility is to attach transponders to the flippers of a large sample of seals. Signals from these seals could then be detected by an aeroplane-mounted receiver during subsequent pup production survey, allowing a mark-recapture estimate of population size. It the ages of tagged seals could be determined at the time of marking, this would provide age-specific population estimates. If a subsequent aerial survey was performed during the moult, a further estimate of population size could be obtained that included size of the male population. However, the necessary tagging and receiving technology for such an exercise is not yet commercially available. It would also be important to determine a protocol for tagging seals that avoids any correlation between probability of marking and recapturing animals. An alternative approach for estimating population size is to combine estimates of numbers of seals hauled out during moult with estimates of the proportion hauled out. Such an approach has its own set of problems. Nevertheless, consideration should be given to this and all other potential approaches.

References

Buckland, S.T., K.B. Newman, L.Thomas and N.B. Koesters. 2004. State-space models for the dynamics of wild animal populations. *Ecological Modelling* 171: 157-175.

Doucet, A., N. de Freitas and N. Gordon [eds.]. 2001. *Sequential Monte Carlo Methods in Practice.* Springer-Verlag, New York.

Duck, C.D. and B.L. Mackey 2005. Grey seal pup production in Britain in 2004. *SCOS Briefing Paper 05/2.*

Hiby, L. and C.D. Duck. Unpublished. Estimates of the size of the British grey seal *Halichoerus grypus* population and levels of uncertainty.

Lui, J.S. 2001. *Monte Carlo Strategies in Scientific Computing.* Springer-Verlag, New York.

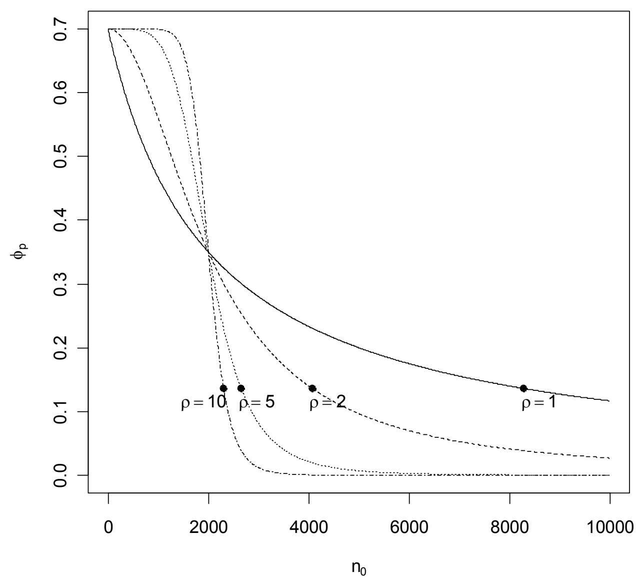
Millar, R.B. 2004. Sensitivity of Bayes estimators to hyper-parameters with an application to maximum yield from fisheries. *Biometrics* 60: 536-542.

Newman, K.B. 2005. Incorporating movement into hidden process models. *Proceedings of 2004 ASA Joint Statistical Meetings*: 2955-2963.

Newman, K.B., C. Fernàndez, S.T. Buckland and L. Thomas. In prep. Inference for state-space models for wild animal populations.
Newman, K.B., S.T. Buckland, S.T. Lindley, L. Thomas and C. Fernàndez. In press. Hidden process models for animal population dynamics. *Ecological Applications*.
Ruxton, G.D. and P. Rohani. 1998. Fitness-dependent dispersal in metapopulations and its consequences for persistence and synchrony. *Journal of Animal Ecology* 67: 530-539.
Shepherd, J.G. 1982. A versatile new stock-recruitment relationship for fisheries and the construction of sustainable yield curves. *Journal du Conseil, Conseil International pour L'Exploration de la Mer* 40: 67-75
Spiegelhalter D. J., Best N. G., Carlin B. P. and van der Linde A. 2002. Bayesian measures of model complexity and fit (with discussion). *Journal of the Royal Statistical Society B*. 64, 583-640.
Thomas, L. and J. Harwood. 2003. Estimating grey seal population size using a Bayesian state-space model. *SCOS Briefing Paper 03/3*.
Thomas, L. and Harwood, J. 2004. A comparison of grey seal population models incorporating density dependent fecundity and pup survival. *SCOS Briefing Paper 04/6*
Thomas, L., S.T. Buckland, K.B. Newman, and J. Harwood. 2005. A unified framework for modelling wildlife population dynamics. *Australian and New Zealand Journal of Statistics* 47: 19-34.

Figure 1. Relationship between pup survival (ϕ_p) and number of pups (n_0) at different levels of ρ in the extended density dependent survival (EDDS) model (formula 1 in text). $\rho = 1$ corresponds with the standard Beverton-Holt density dependent function. The relationship between fecundity and number of 6+ females has the same shape in the extended density dependent fecundity (EDDF) model (formula 2).

(a) Filled circles show the number of pups at carrying capacity at the given level of ρ (formula 3) with the other model parameters fixed ($\beta = 0.0005$, $\alpha = 0.95$, $\phi_{p\max} = 0.7$, and $\alpha_a = 0.95$).



(b) Labels show the level of β required for a fixed carrying capacity of 8000 (formula 3, $\chi = 8000$, $\alpha = 0.95$, $\phi_{p\max} = 0.7$, and $\alpha_a = 0.95$).

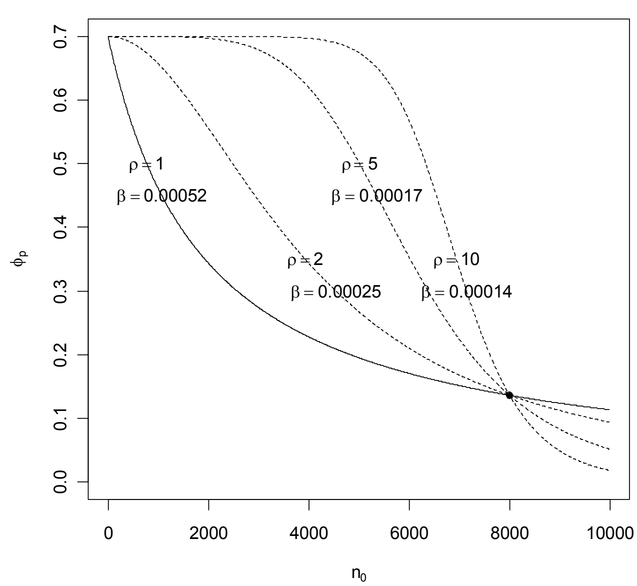
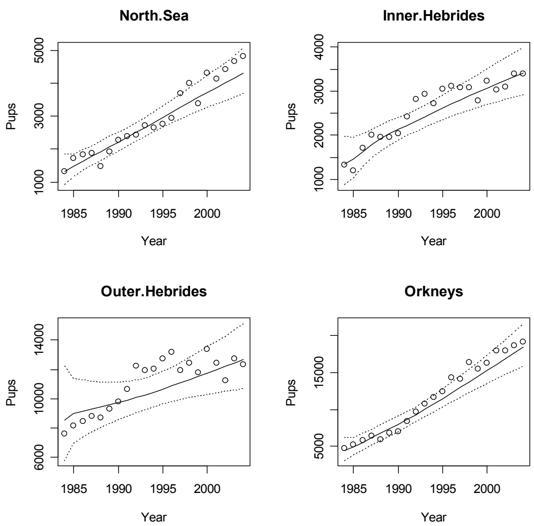
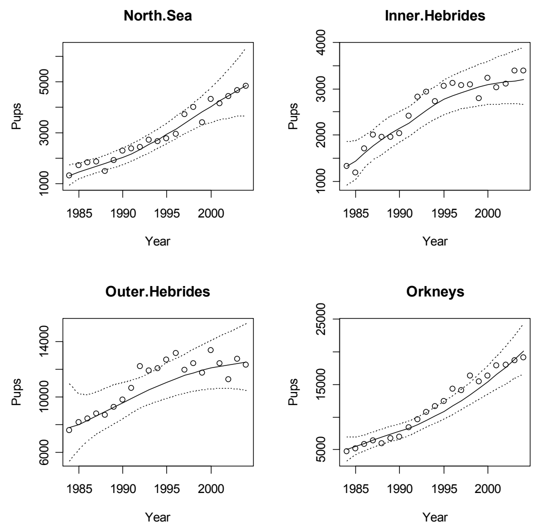


Figure 2. Estimates of true pup production from four models of grey seal population dynamics fit to pup production estimates from 1984-2004. Input data are shown as circles, while the lines show the posterior mean bracketed by the 95% credibility interval.

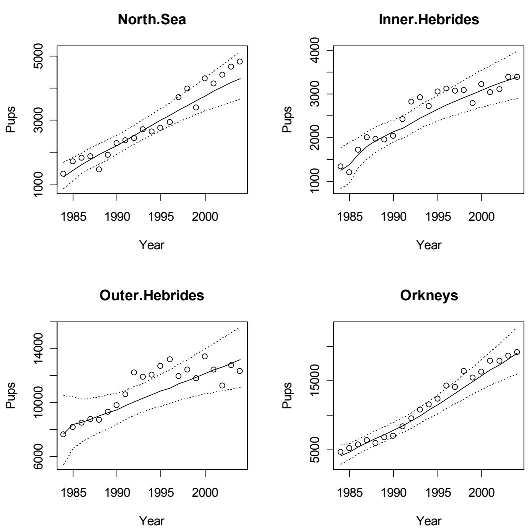
(a) Density dependent survival (DDS)



(b) Extended density dependent survival (EDDS)



(c) Density dependent fecundity (DDF)



(d) Extended density dependent fecundity (EDDF)

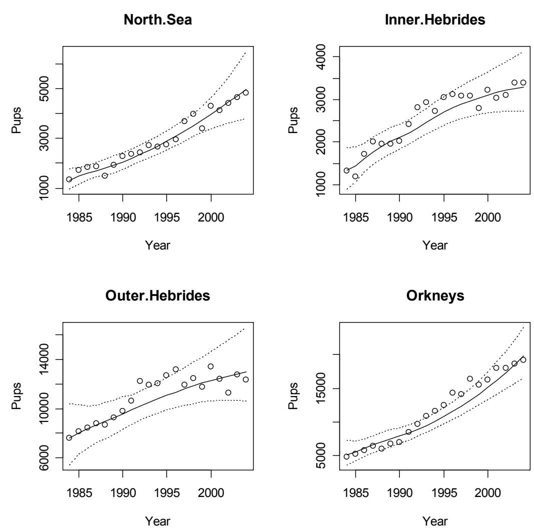
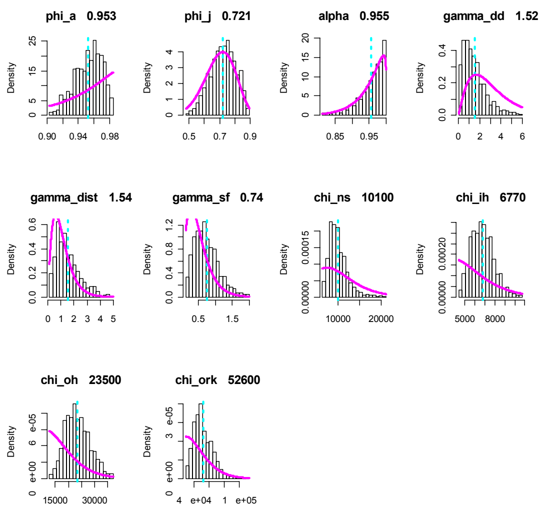
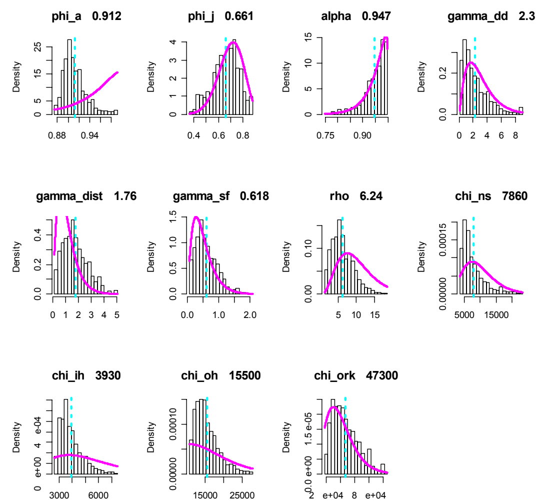


Figure 3. Posterior parameter estimates (histograms) and priors (solid lines) from four models of grey seal population dynamics fit to pup production estimates from 1984-2004. The vertical line shows the posterior mean, its value is given in the title of each plot after the parameter name.

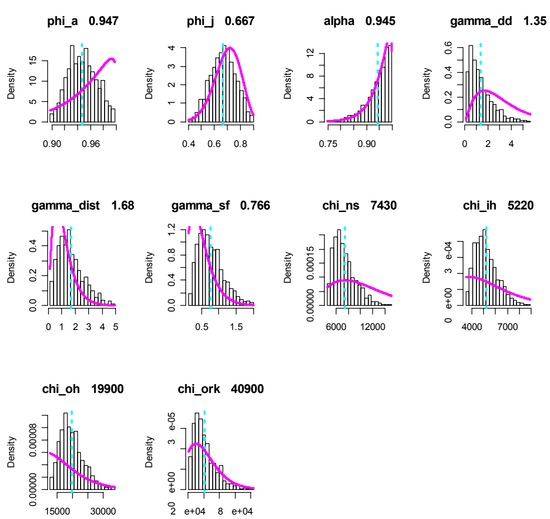
(a) Density dependent survival (DDS)



(b) Extended density dependent survival (EDDS)



(c) Density dependent fecundity (DDF)



(d) Extended density dependent fecundity (EDDF)

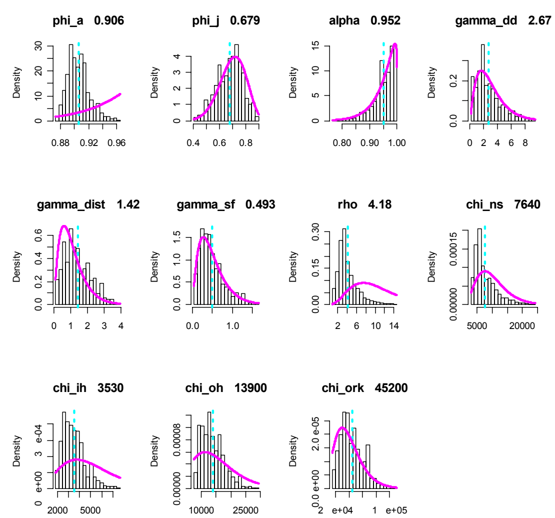
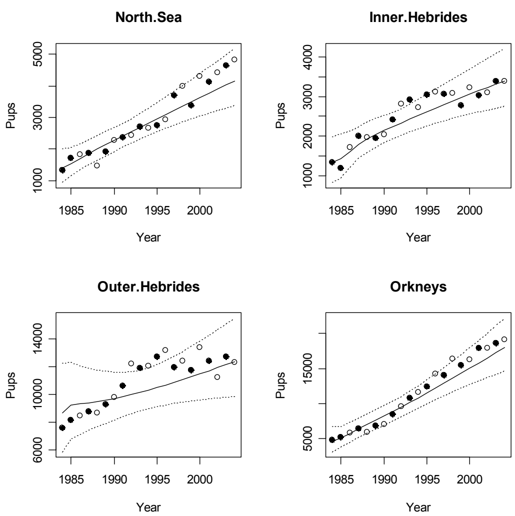
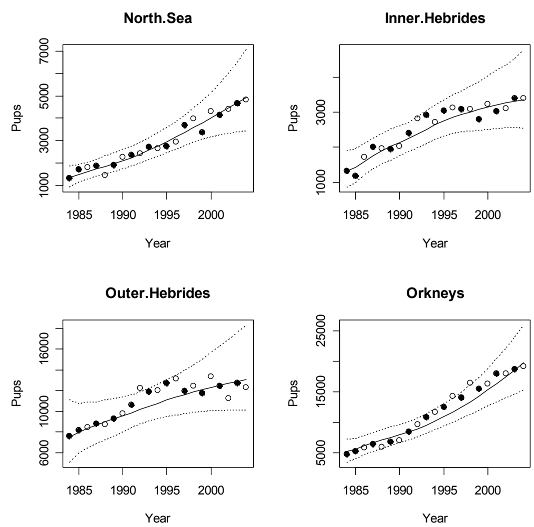


Figure 4. Estimates of true pup production from four models of grey seal population dynamics, fit to pup production estimates from 1984, 1985, 1987, 1989, 1991, 1993, 1995, 1997, 1999, 2001 and 2003. Input data are shown as filled circles and excluded data as empty circles. Lines show the posterior mean bracketed by the 95% credibility interval.

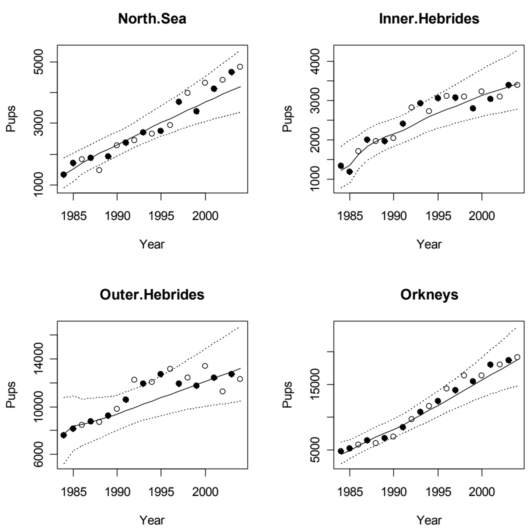
(a) Density dependent survival (DDS)



(b) Extended density dependent survival (EDDS)



(c) Density dependent fecundity (DDF)



(d) Extended density dependent fecundity (EDDF)

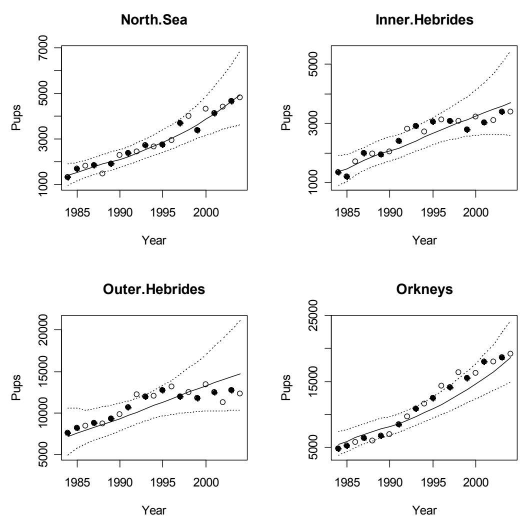
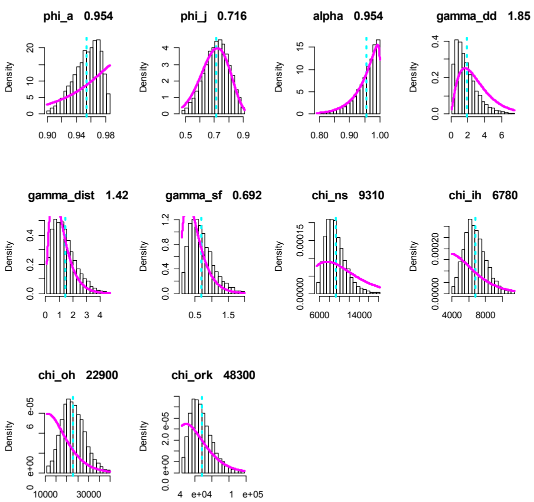
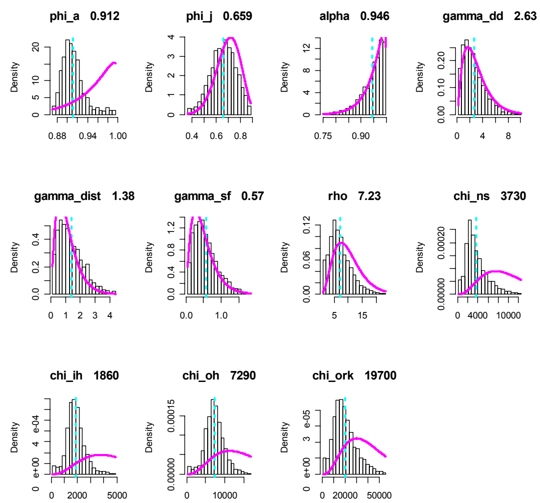


Figure 5. Posterior parameter estimates (histograms) and priors (solid lines) from four models of grey seal population dynamics fit to pup production estimates from 1984, 1985, 1987, 1989, 1991, 1993, 1995, 1997, 1999, 2001 and 2003. The vertical line shows the posterior mean, its value is given in the title of each plot after the parameter name.

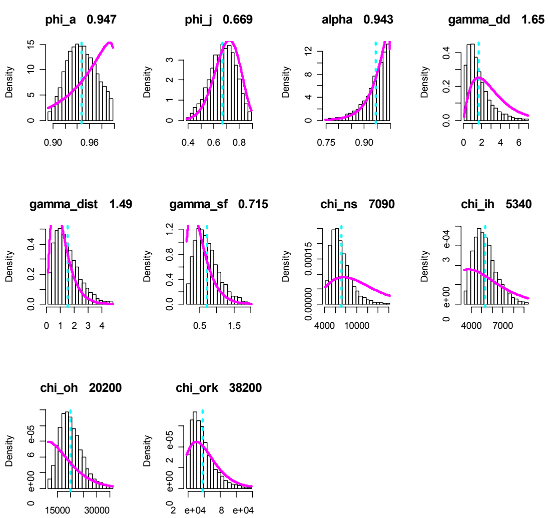
(a) Density dependent survival (DDS)



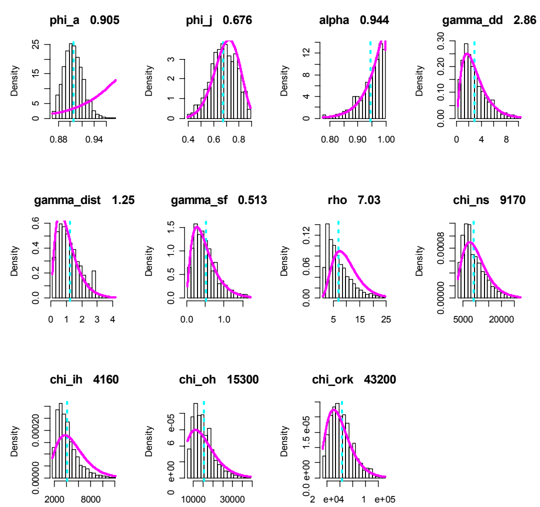
(b) Extended density dependent survival (EDDS)



(c) Density dependent fecundity (DDF)



(d) Extended density dependent fecundity (EDDF)



Appendix

Estimates of total population size, in thousands, at the beginning of each breeding season from 1984-2004, made using four model of British grey seal population dynamics. Numbers are posterior means followed by 95% credibility intervals in brackets.

Density dependent survival model

Year	North Sea	Inner Hebrides	Outer Hebrides	Orkneys	Total
1984	4.4 (3.4 5.8)	4.4 (3.1 6)	24.4 (19 32.7)	15.8 (12 20.9)	49 (37.5 65.3)
1985	4.8 (3.8 6.1)	4.7 (3.6 6.2)	24.6 (19.5 32.4)	17.2 (13.5 22.2)	51.2 (40.3 66.8)
1986	5.2 (4.2 6.5)	5 (3.9 6.4)	24.8 (19.9 32.4)	18.7 (15 23.6)	53.6 (43 68.8)
1987	5.5 (4.5 6.9)	5.3 (4.2 6.7)	25.1 (20.2 32.7)	20.3 (16.5 25.5)	56.2 (45.5 71.8)
1988	5.9 (4.8 7.4)	5.5 (4.4 7.1)	25.4 (20.5 32.8)	22 (17.9 27.3)	58.8 (47.7 74.5)
1989	6.3 (5.1 7.8)	5.8 (4.7 7.3)	25.8 (20.8 33.1)	23.7 (19.3 29.1)	61.5 (50 77.3)
1990	6.7 (5.4 8.3)	6 (4.9 7.7)	26.2 (21.1 33.4)	25.4 (20.8 31.5)	64.3 (52.2 80.8)
1991	7 (5.7 8.8)	6.3 (5.1 8)	26.5 (21.3 33.7)	27.2 (22.3 33.7)	67.1 (54.4 84.1)
1992	7.4 (6 9.3)	6.5 (5.2 8.3)	27 (21.6 34.2)	29 (23.7 35.9)	69.9 (56.5 87.7)
1993	7.8 (6.3 9.8)	6.7 (5.4 8.5)	27.4 (21.8 34.9)	30.9 (25.1 38.4)	72.8 (58.5 91.5)
1994	8.2 (6.6 10.3)	7 (5.5 8.8)	27.8 (22 35.5)	32.7 (26.4 40.7)	75.6 (60.5 95.4)
1995	8.5 (6.8 10.8)	7.2 (5.7 9.1)	28.3 (22.1 36.4)	34.6 (27.8 43.5)	78.6 (62.5 99.8)
1996	8.9 (7.1 11.3)	7.4 (5.8 9.4)	28.7 (22.3 37.2)	36.5 (29.1 46.1)	81.5 (64.4 104.1)
1997	9.2 (7.3 11.9)	7.6 (6 9.7)	29.2 (22.6 38.2)	38.4 (30.4 49)	84.4 (66.2 108.9)
1998	9.6 (7.6 12.5)	7.8 (6.1 10)	29.7 (22.8 38.9)	40.3 (31.7 52.1)	87.3 (68.1 113.4)
1999	9.9 (7.8 13.1)	8 (6.2 10.2)	30.2 (22.9 39.9)	42.2 (32.9 54.9)	90.3 (69.8 118.1)
2000	10.3 (8 13.6)	8.2 (6.3 10.5)	30.7 (23.2 40.9)	44.1 (34.1 57.8)	93.2 (71.6 122.8)
2001	10.6 (8.2 14.2)	8.4 (6.5 10.8)	31.2 (23.4 41.8)	46 (35.3 60.6)	96.1 (73.3 127.3)
2002	10.9 (8.5 14.7)	8.5 (6.6 11)	31.7 (23.6 42.7)	47.8 (36.4 63.7)	99 (75.1 132.1)
2003	11.3 (8.7 15.3)	8.7 (6.7 11.3)	32.2 (23.8 43.4)	49.7 (37.5 66.7)	101.9 (76.7 136.7)
2004	11.6 (8.9 15.8)	8.9 (6.8 11.6)	32.7 (24 44.2)	51.5 (38.6 69.8)	104.7 (78.3 141.4)

Extended density dependent survival model

Year	North Sea	Inner Hebrides	Outer Hebrides	Orkneys	Total
1984	5.3 (3.8 6.7)	5.4 (3.7 7.2)	28.7 (20 37.7)	21 (14.1 27.6)	60.4 (41.6 79.1)
1985	5.6 (4.2 7)	5.8 (4.1 7.5)	29.8 (20.7 38.3)	22.1 (15.4 28.5)	63.2 (44.5 81.3)
1986	5.9 (4.5 7.4)	6.1 (4.5 7.9)	30.9 (21.7 39.3)	23.3 (16.9 29.5)	66.3 (47.5 84.1)
1987	6.3 (4.9 7.8)	6.5 (4.8 8.2)	32.1 (22.4 40.4)	24.7 (18.3 30.9)	69.7 (50.4 87.3)
1988	6.8 (5.2 8.3)	7 (5.1 8.7)	33.2 (22.7 41.5)	26.3 (19.9 32.5)	73.3 (52.9 91)
1989	7.2 (5.6 8.8)	7.5 (5.5 9.2)	34.3 (23.1 42.6)	28 (21.4 34.4)	77.1 (55.5 95)
1990	7.7 (6 9.4)	7.9 (5.7 9.7)	35.4 (23.3 43.6)	29.9 (23.2 36.4)	80.9 (58.2 99.2)
1991	8.3 (6.3 10.1)	8.4 (6 10.3)	36.3 (23.7 44.7)	31.8 (24.9 38.7)	84.8 (60.9 103.8)
1992	8.9 (6.8 10.7)	8.8 (6.1 10.9)	37.2 (24.3 46)	33.9 (26.6 41.1)	88.8 (63.8 108.7)
1993	9.5 (7.1 11.5)	9.2 (6.3 11.5)	38 (24.8 47)	36.2 (28.3 43.7)	92.8 (66.5 113.7)
1994	10.2 (7.6 12.4)	9.5 (6.5 11.9)	38.7 (25.2 48.2)	38.6 (30.1 46.7)	97 (69.3 119.2)
1995	10.9 (7.9 13.3)	9.8 (6.6 12.4)	39.3 (25.4 49.5)	41.3 (32.1 50)	101.2 (71.9 125.1)
1996	11.6 (8.1 14.2)	10 (6.7 12.6)	39.8 (25.8 50.6)	44.2 (34.1 53.7)	105.5 (74.7 131.2)
1997	12.4 (8.3 15.3)	10.1 (6.8 12.9)	40.2 (26.1 51.8)	47.3 (35.9 57.4)	109.9 (77.2 137.3)
1998	13.2 (8.6 16.4)	10.2 (6.8 13.2)	40.5 (26.3 52.5)	50.6 (37.8 61.8)	114.4 (79.5 143.8)
1999	13.9 (8.7 17.5)	10.3 (6.8 13.4)	40.7 (25.8 53.1)	54.2 (39.7 66.2)	119 (81 150.2)
2000	14.6 (9 18.8)	10.3 (6.8 13.6)	40.9 (26.1 54)	57.9 (41.3 70.9)	123.7 (83.2 157.3)
2001	15.2 (9.1 20.2)	10.4 (6.8 13.9)	41.2 (26.2 54.7)	61.8 (42.8 75.9)	128.6 (84.9 164.7)
2002	15.9 (9.3 21.6)	10.4 (6.8 14)	41.4 (26.3 55.6)	65.9 (44.1 81.4)	133.6 (86.4 172.6)
2003	16.5 (9.4 23.1)	10.5 (6.8 14.3)	41.6 (26.5 56.5)	70.2 (44.7 87.7)	138.7 (87.5 181.5)
2004	17 (9.5 24.8)	10.6 (6.8 14.5)	41.8 (27 57.4)	74.5 (45.7 94.4)	143.9 (89 191.1)

Density dependent fecundity model

Year	North Sea	Inner Hebrides	Outer Hebrides	Orkneys	Total
1984	5.7 (4.1 7.9)	6 (3.8 8.9)	40.1 (27.6 60.1)	18.2 (13.3 24.4)	70 (48.8 101.3)
1985	6.2 (4.7 8.5)	6.6 (4.7 9.4)	41.4 (29.2 60.9)	20.1 (15.1 26.5)	74.4 (53.7 105.3)
1986	6.9 (5.3 9.2)	7.4 (5.4 10)	43 (31.2 61.8)	22.3 (17.1 28.7)	79.6 (59 109.8)
1987	7.7 (5.9 10.1)	8.1 (6.1 10.7)	44.8 (33.1 62.6)	24.8 (19.4 31.6)	85.3 (64.5 115.1)
1988	8.4 (6.5 11)	8.9 (6.9 11.6)	46.6 (35 64.2)	27.5 (21.6 35.1)	91.4 (69.9 121.9)
1989	9.3 (7.2 12)	9.6 (7.5 12.5)	48.5 (36.7 66.5)	30.5 (24 38.8)	97.9 (75.3 129.8)
1990	10.1 (7.9 13.1)	10.4 (8.2 13.4)	50.4 (38.3 69)	33.7 (26.4 42.9)	104.6 (80.9 138.4)
1991	11 (8.6 14.3)	11.2 (8.8 14.6)	52.4 (39.8 71.1)	37.1 (29.1 47.4)	111.7 (86.2 147.4)
1992	11.9 (9.3 15.7)	11.9 (9.4 15.7)	54.5 (41.2 74.9)	40.7 (31.9 52.4)	119.1 (91.8 158.7)
1993	12.9 (10.1 17)	12.7 (9.9 16.9)	56.6 (42.6 77.9)	44.6 (34.9 57.9)	126.9 (97.5 169.8)
1994	13.9 (10.9 18.5)	13.5 (10.4 18.1)	58.9 (44.1 81.5)	48.8 (37.9 64.3)	135 (103.3 182.3)
1995	14.9 (11.7 20.1)	14.2 (10.9 19.4)	61.2 (45.6 85.6)	53.2 (41.3 70.7)	143.5 (109.5 195.8)
1996	16 (12.5 21.8)	15 (11.4 20.6)	63.6 (47.6 89.1)	57.8 (44.6 78.3)	152.4 (116.1 209.8)
1997	17.1 (13.1 23.5)	15.8 (11.9 21.9)	66.1 (49.1 93.3)	62.6 (48 85.2)	161.6 (122.2 223.9)
1998	18.2 (14 25.3)	16.6 (12.4 23.4)	68.6 (50.7 97.6)	67.7 (51.5 93.2)	171.1 (128.5 239.5)
1999	19.3 (14.7 27.1)	17.4 (12.8 24.9)	71.1 (52.1 102.5)	73 (55 101.1)	180.9 (134.6 255.6)
2000	20.5 (15.4 28.9)	18.2 (13.3 26.3)	73.8 (53.4 107.8)	78.6 (59 109.1)	191 (141.1 272.1)
2001	21.6 (16.2 30.7)	19 (13.8 27.8)	76.5 (54.5 113.3)	84.3 (62.6 116.7)	201.4 (147 288.5)
2002	22.8 (16.9 32.5)	19.8 (14.2 29.3)	79.2 (56.1 119.3)	90.2 (66.6 125.4)	212.1 (153.9 306.6)
2003	24 (17.7 34.2)	20.6 (14.7 30.8)	82 (57.3 124.9)	96.3 (71 134.4)	222.9 (160.7 324.3)
2004	25.3 (18.5 36.1)	21.4 (15.1 32.3)	84.9 (58.7 131.5)	102.5 (75.3 144.4)	234.1 (167.6 344.2)

Extended density dependent fecundity model

Year	North Sea	Inner Hebrides	Outer Hebrides	Orkneys	Total
1984	5.4 (3.9 7)	5.7 (4.1 7.8)	31.3 (22.7 43.1)	21.8 (16 28.8)	64.3 (46.8 86.8)
1985	5.7 (4.2 7.4)	6.1 (4.6 8)	32.5 (24.1 44)	22.9 (17.6 29.6)	67.2 (50.5 89)
1986	6.1 (4.6 7.8)	6.4 (5 8.5)	33.8 (25.5 45.2)	24.1 (19 30.8)	70.5 (54.1 92.3)
1987	6.6 (5 8.3)	6.9 (5.5 8.9)	35.1 (27 46.2)	25.6 (20.6 32.4)	74.2 (58.1 95.9)
1988	7.1 (5.4 8.9)	7.4 (5.9 9.5)	36.5 (28.4 47)	27.2 (22 34.2)	78.2 (61.7 99.5)
1989	7.6 (5.8 9.5)	7.9 (6.4 10)	37.9 (29.8 48.4)	29 (23.5 36.1)	82.3 (65.5 104)
1990	8.1 (6.3 10.3)	8.4 (6.8 10.5)	39.3 (31.2 50)	30.9 (25.2 38.4)	86.7 (69.4 109.3)
1991	8.7 (6.7 11)	8.9 (7.2 11.2)	40.7 (32.5 51.5)	32.9 (26.9 40.5)	91.2 (73.3 114.2)
1992	9.3 (7.1 11.8)	9.4 (7.6 11.7)	42.1 (33.8 52.8)	35 (28.8 42.6)	95.8 (77.3 118.8)
1993	9.9 (7.6 12.6)	10 (8.1 12.3)	43.5 (35.1 54.3)	37.3 (30.9 45.2)	100.8 (81.6 124.4)
1994	10.7 (8.2 13.6)	10.5 (8.5 12.9)	44.9 (36.4 56)	39.8 (32.9 47.9)	105.9 (86 130.4)
1995	11.4 (8.9 14.5)	11 (8.9 13.6)	46.3 (37.6 58)	42.6 (35.1 51.2)	111.3 (90.5 137.3)
1996	12.3 (9.7 15.5)	11.5 (9.3 14.3)	47.7 (38.6 59.6)	45.5 (37.3 55)	116.9 (94.9 144.5)
1997	13.1 (10.5 16.6)	12 (9.7 15.1)	49.1 (39.5 61.8)	48.7 (39.8 59.6)	122.9 (99.5 153)
1998	14 (11.3 17.6)	12.4 (10 15.7)	50.4 (40.4 63.8)	52.1 (42.5 64.5)	129 (104.2 161.6)
1999	15 (12.1 18.6)	12.9 (10.2 16.3)	51.7 (41.2 65.7)	55.7 (44.9 69.6)	135.4 (108.4 170.2)
2000	16 (12.8 19.8)	13.3 (10.5 17.1)	53 (42 68.3)	59.7 (48 74.9)	142 (113.3 180.1)
2001	17.1 (13.7 21.3)	13.6 (10.7 17.9)	54.2 (42.6 70.5)	64 (51.4 80.9)	148.9 (118.4 190.5)
2002	18.1 (14.4 23)	14 (10.9 18.7)	55.3 (43.3 72.6)	68.6 (54.8 86.8)	156 (123.4 201)
2003	19.2 (15.1 24.6)	14.3 (11.1 19.3)	56.5 (43.7 75.1)	73.5 (58.1 94.4)	163.5 (128 213.3)
2004	20.4 (15.6 26.6)	14.6 (11.3 20)	57.5 (43.9 77.3)	78.7 (61.8 101.5)	171.2 (132.5 225.4)

J. Matthiopoulos & G. Aarts

Update on the distribution of grey seals outside the breeding season

NERC Sea Mammal Research Unit, Gatty Marine Laboratory, University of St Andrews, St Andrews KY16 8LB

Summary

Resolution of conflicts between conservation and management of grey seals requires detailed knowledge of their at-sea distribution. Previous work has focused on developing the methodology for this and using historical telemetry and aerial survey data. The same work has highlighted geographical gaps in our data and motivated further data collection in the Irish sea. Here, we report on the analysis of these new data.

1. Introduction

The extent of overlap between seal foraging and human activity depends on the fine-scale spatial distribution of the seals' foraging effort. In previous work, Matthiopoulos *et al.* (2004) synthesized existing telemetry data on offshore movements and aerial survey data on haulout counts into a reliable map of the use of space by those grey seals associated with the UK coasts and waters (Fig 1). By estimating sampling effort over space, the same work had highlighted geographical gaps in our knowledge (Fig. 2) particularly off the coast of Wales and the Irish sea. This motivated further data collection and analysis focusing in these areas.

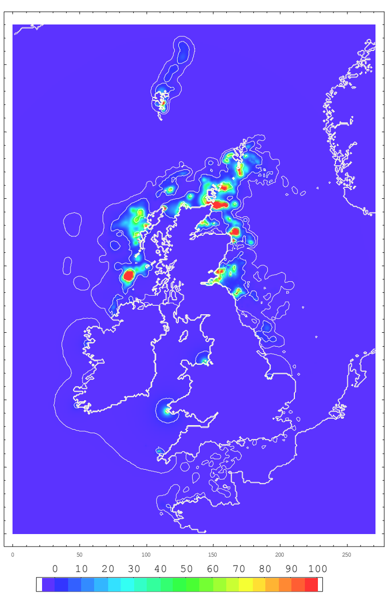


Figure 1: Distribution of the UK population of grey seals

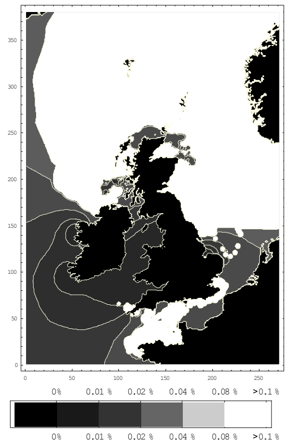


Figure 2: Estimated percentage of population usage sampled by satellite tags until 2003.

2. Methods & Results

We used data from 17 animals tagged at or around the Irish sea. The data set comprised 20,360 locations which we allocated to return trips from 7 haulout regions. We then used auxiliary information on seal movement (speed, trip duration, locations of haulouts, obstacles to movement) to estimate the relative accessibility (Matthiopoulos 2003a) of marine locations from each haulout region.

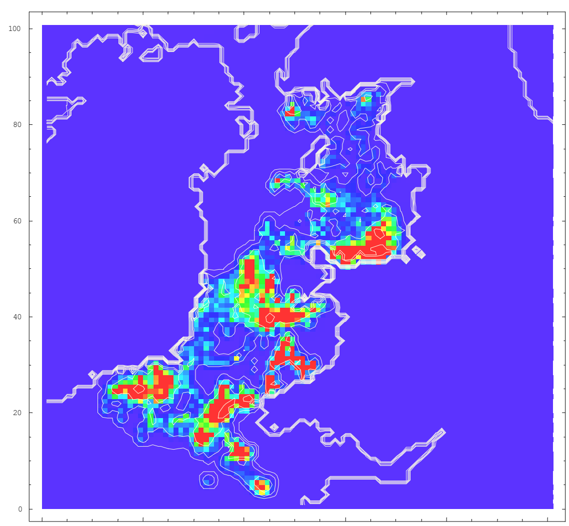


Figure 3: Usage estimates for marine locations in the Irish sea

Maps of accessibility were used to supervise non-parametric surface-fitting (Matthiopoulos 2003b) on satellite telemetry data hence providing a map of the marine usage radiating from each haulout region.

Maps of usage from each haulout region were weighted by the numbers of animals associated with it. These were then superimposed to yield the aggregate map of usage for the entire region of interest (Fig. 3).

3 Discussion

Data collection from the Irish Sea forms part of a greater survey effort on the west coast of Britain. Upon completion of this work, new versions of Figs 1 and 2 will be produced incorporating all the new data. In the meantime, this preliminary analysis of the Irish data has identified previously unknown hotspots of marine usage and of potential overlap with human activity.

References

Matthiopoulos, J. (2003a) The use of space by animals as a function of accessibility and preference. -*Ecological Modelling* 159: 239-268.

Matthiopoulos, J. (2003b) Model-supervised kernel smoothing for the estimation of spatial usage. *Oikos* 102: 367-377.

Matthiopoulos, J., McConnel, B., Fedak, M. & Duck, C. (2004) Using satellite telemetry and aerial counts to estimate space use by grey seals around the British isles. *Journal of Applied Ecology*. 41, 76-4

C.D. Duck, D. Thompson & L. Cunningham

The Status of British Common Seal Populations

NERC Sea Mammal Research Unit, Gatty Marine Lab, University of St Andrews, St Andrews, Fife KY16 8LB

Summary

In August 2004, SMRU conducted surveys of common seals in Lincolnshire and Norfolk in England; the Firth of Tay, the Moray Firth and around Skye in Scotland. One survey in eastern England was during the breeding season, the remaining surveys were all during the common seal annual moult, in August. Scottish sites were surveyed repeatedly to determine the variation in numbers of seals ashore during the survey period but fog on the Scottish east coast restricted the number of successful surveys.

Counts of common seals in the Wash were 14.6% lower than 2003 and 28% lower than pre-epidemic counts in 2002. Counts at other Lincolnshire and Norfolk sites were similar to pre-epidemic counts.

In the Moray Firth, numbers counted in 2004 were very similar to 2003. In the Firth of Tay, numbers were similar to 2003 but lower than in previous years.

Introduction

SMRU's surveys of common seals are carried out during their annual moult, in August. The Lincolnshire and Norfolk coast, which holds >95% of the English common seal population, is surveyed annually, usually twice. Surveys of the Scottish coast are undertaken on an approximately five-yearly cycle, although some areas are surveyed more frequently than this (e.g. Moray Firth and Firth of Tay).

Surveys are carried out during the annual moult, in August. At this time during their annual cycle, common 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 therefore not counted. Thus the numbers presented here represent the minimum number of common seals in each area and are used as an index of population size.

In addition, English Nature funded a breeding season survey (in early July) of common seals in Lincolnshire and Norfolk, including The Wash.

Methods

Surveys of the estuarine haulout sites on the east coast of Britain were made using large format vertical aerial photography from a twin-engined fixed-wing aircraft. On sandbanks, seals are relatively easily located and this method of survey is highly cost-effective. 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. Surveys on Skye were with a helicopter-mounted thermal imaging camera.

Again, we intended to survey the Moray Firth and the Firth of Tay on successive days to determine the variation in numbers of seals hauled ashore. Unfortunately, we could not conduct or complete a number of surveys due to persistent sea fog settling in the Firths.

Results

1. Common seals surveys in eastern England

In 1988, the numbers of common 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 (Figure 1, Table 1).

Two aerial surveys of common seals were carried out in Lincolnshire and Norfolk during August 2004 (Table 1). The mean 2004 count for The Wash (2146) was 14.6% lower than the mean 2003 count (2513) and 28% lower than the mean pre-epidemic 2002 count (2976).

We developed two population growth models that explicitly modelled variability in both observation and population growth processes (Thompson, Duck & Lonergan (submitted). We were able to show that uncertainty in proportion of animals observed dominates in this system, allowing growth rates within each period to be treated as constant. The two population trajectory models produced encouragingly similar results. The population was increasing at a little over 3% pa until 1988 (95% CI: 2.1-4.1(state space model (SSM)), 2.5-4.5 (GLM)) (Figure 2). 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 (95% CI: 44-59(SSM), 48-62(GLM)), coincident with the PDV epidemic. After 1989 the number increased again, at almost 6% pa (95% CI: 4.8-6.7(SSM), 5.1-6.8(GLM)). The post epidemic rate of increase was significantly higher than the pre epidemic rate ($p<0.001$, pair-wise comparison of parameter estimates). The population was affected by a recurrence of the PDV epidemic in August 2002. The first indications of morbidity due to the epidemic were reported in early August, shortly after the 2002 survey. The dates of the surveys and the disease outbreak in 2002 were almost exactly the same as in 1988. However mortality was lower than in 1988, at around 22% (95% CI: 9-33(SSM), 11-33(GLM)).

As the time series of counts at both Blakeney and Donna Nook are sparse in comparison to the Wash they have not been subjected to the same analysis. The mean 2004 count at Donna Nook was 27% higher than the 2003 count and 14% lower than the mean pre-epidemic 2002 count. The mean 2004 count at Blakeney was 62% higher than the 2003 count and 32% higher than the mean pre-epidemic 2002 count (Table 1).

Overall, the combined count for the English East coast population in 2004 was 2% lower than in 2003. This apparent lack of recovery contrasts with the rapid recovery of the Wadden Sea population that is apparently increasing at around 15% p.a. A similar pattern was observed after the 1988 epidemic with the English population showing a delayed and/or slower recovery compared with the rest of Europe.

A total of 613 pups and 1766 older harbour seals (1+ age classes) were counted in the Wash during the 2004 breeding season survey. The 2004 pup count was 12% higher than the 2001 pup count (548 pups). The 2004 adult count was 2% lower than the equivalent 2001 count. Slight differences in timing of surveys mean that direct comparisons are problematic, but there is no indication of a major decline in pup production after the 2002 PDV epidemic.

The distribution of pups was generally similar to that seen in 2001. Pups were widely distributed within the Wash, being present at all 23 occupied haulout sites. As in 2001, no pups were detected at Blakeney and only one at Donna Nook, with 8 pups at Scroby Sands.

2. Common seals in Scotland

In August 2004, areas surveyed for common seals included the Inner Moray Firth, the Firth of Tay and parts of the coast around Skye.

Moray Firth

SMRU's aerial surveys of this area began in August 1992. The counts are in Table 2, and the trends are shown in Figure 3. The first count in 2004 for the Inner Moray Firth was lower than in 2003 while the second was virtually the same. Numbers of seals at Findhorn were the lowest since 1997. On the first survey no seals were seen, nor were there any signs of seals on the sandbanks. Numbers at Loch Fleet continued to increase. Paul Thompson, from Aberdeen University's Lighthouse Field Station, in Cromarty, has more detailed annual counts of common seals in the Inner Moray Firth in the summer months since 1988.

Tay Estuary

The 2004 harbour seal total for the Firth of Tay was similar to the 2003 count (Table 3). Counts for the last two years were the lowest since 1990 (Figure 4). Despite similar totals for the last two years, the distribution of animals has changed within the Firth. The biggest changes were in the Eden Estuary, Abertay and Tentsmuir, and at Buddon Ness. Although the first two locations are susceptible to disturbance by trippers walking on the beach, there was no obvious evidence of any recent disturbance (i.e. there were no obvious traces of seals having been hauled ashore at frequently used haulout sites, or of human footprints going to and from these locations).

Skye

Common seals in the north-west Skye SAC and in areas around east Skye were surveyed every day from 1 to 6 August 2004. The numbers of seals seen in the SAC and in the other areas surveyed are in Table 4. Over the survey interval, the number of common seals in the SAC increased. Since 1988, numbers of common seals in the north-west Skye SAC have varied between 272 (1992) and 968 in 2000, although the majority of counts have been consistently around 600 to 650.

4. Minimum estimate of the size of the British common seal population

The most recent minimum estimate of the number of common seals in Scotland is 29,579 from surveys carried out in 1996, 1997, 2000, 2001, 2002, 2003 and 2004. The most recent minimum estimate for England is 3,517. This comprises 3,292 seals in Lincolnshire and Norfolk in 2004 plus 225 seals in Northumberland, Cleveland, Essex and Kent between 1994 and 2003 and an estimated 20 seals from the south and west coasts.

Table 5 contains counts by region for the period 1996-2004. These are presented as the most recent counts available for each region. Where multiple counts were obtained in any August (in The Wash, for example), the mean values have been used. Table 6 includes numbers from Ireland, both the North and the Republic. The distribution of harbour seals in Great Britain and Ireland is shown in Figure 2. Data have been aggregated into 10km squares.

5. Common seal surveys proposed for 2005 and 2006

In August 2005 we started a new Scottish-wide survey of harbour seals. Using a helicopter and a thermal imaging camera, we have completed the Scottish west coast from Duncansby Head to Loch Linnhe, including the inner islands and from Machrihanish to Silloth, in Cumbria. We intend tocomplete the Scottish east coast, from the Farne Islands to Duncansby Head in the next few days.

In England, a second breeding season survey of Lincolnshire and Norfolk was completed (by fixed-wing aircraft). Two moult surveys of this area were completed in August with additional surveys of the Firth of Tay and the Moray Firth.

In 2006, assuming finaces permit, we plan to survey Shetland, Orkney, the Western Isles and the remainder of Strathclyde to complete our second full survey of Scotland using a helicopter equipped with thermal imager.

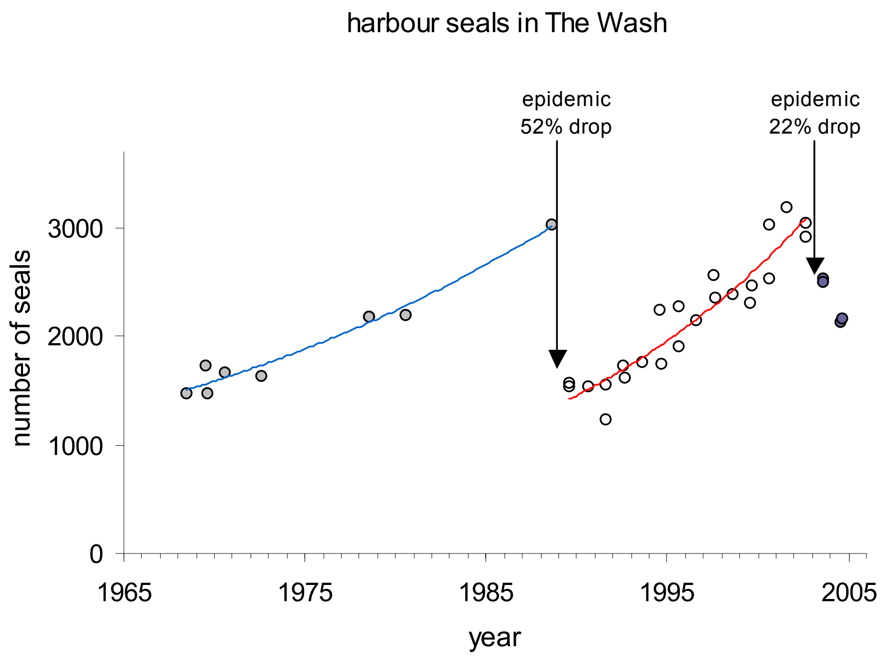


Figure 1. **Counts of common seals in The Wash in August. These data are an index of the population size through time. Fitted lines are exponential growth curves (growth rates given in text).**

Figure 2. The August distribution of harbour seals in Great Britain and Ireland, by 10km squares. These data are from surveys carried out between 1996 and 2003.

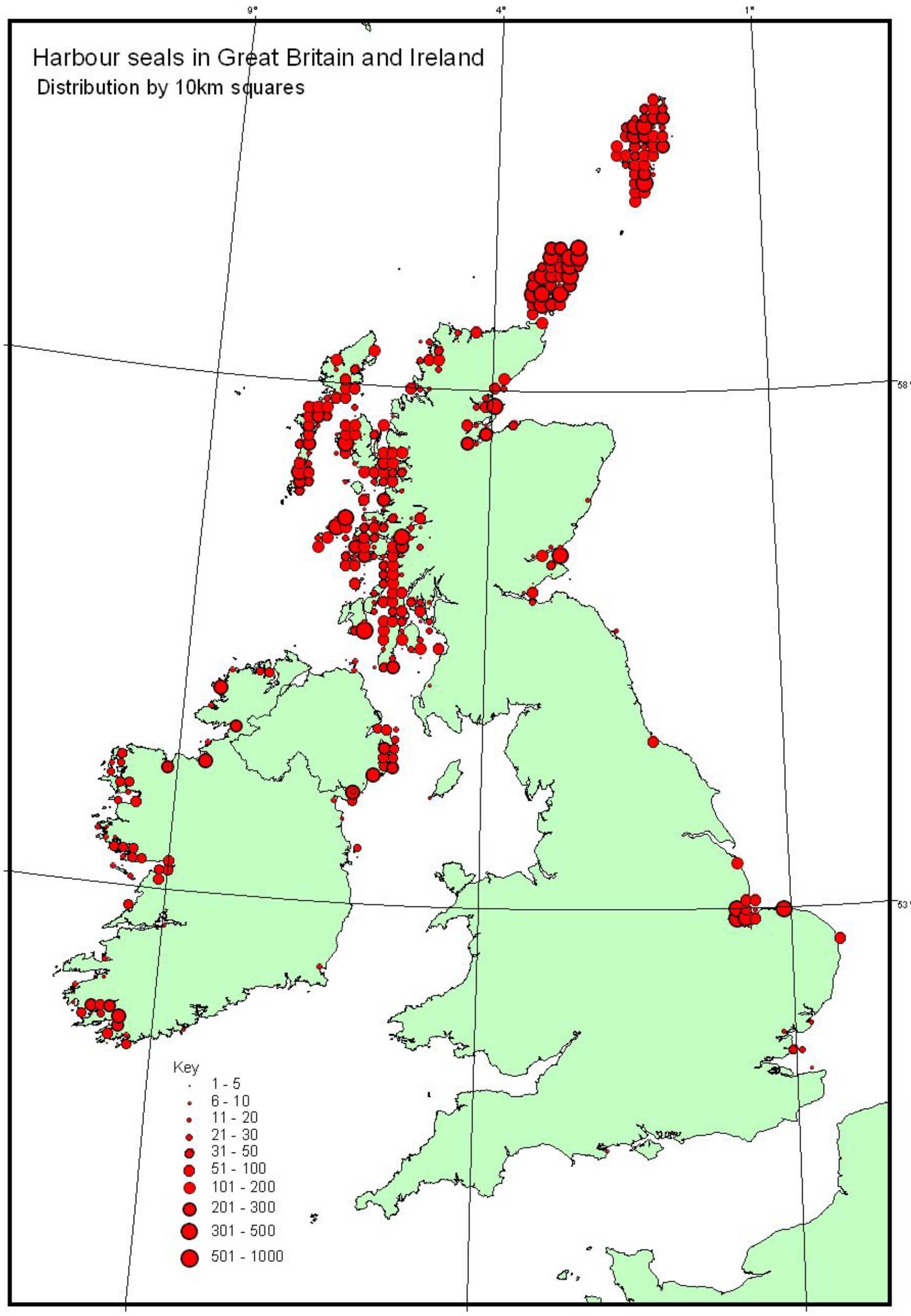


Figure 3 Common seals in the Firth of Tay

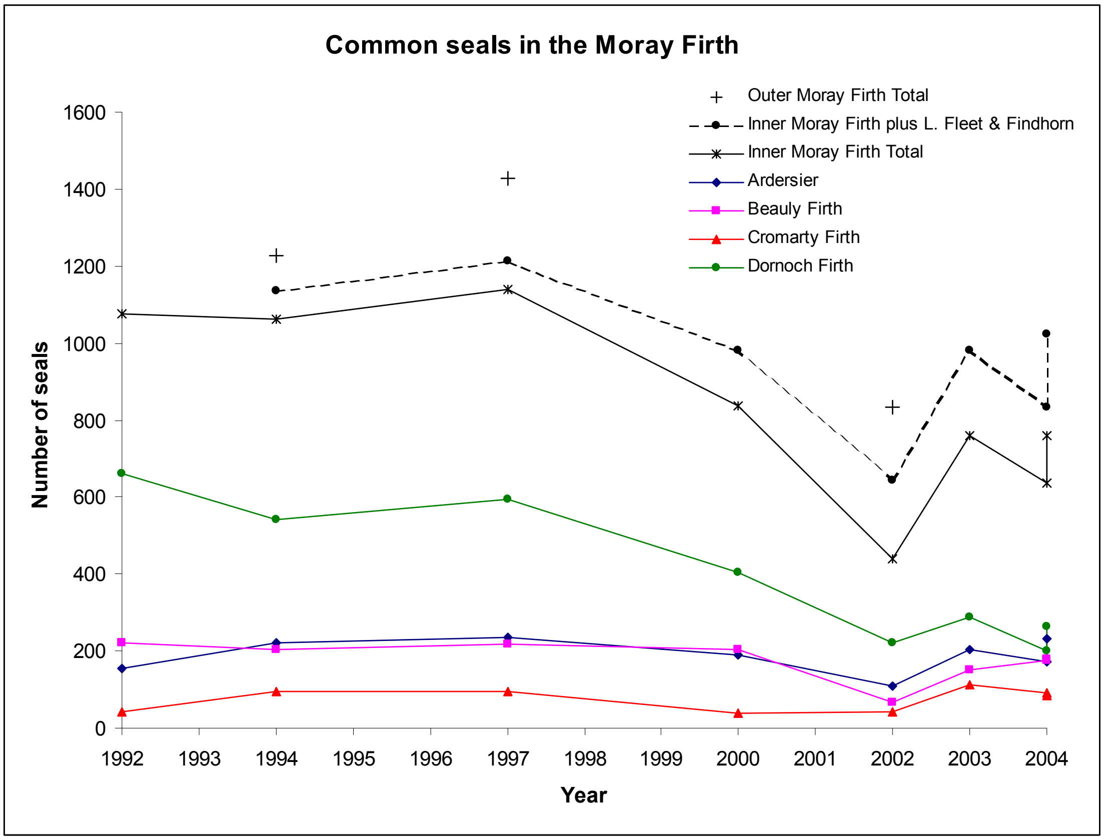


Figure 4 Common seals in the Firth of Tay

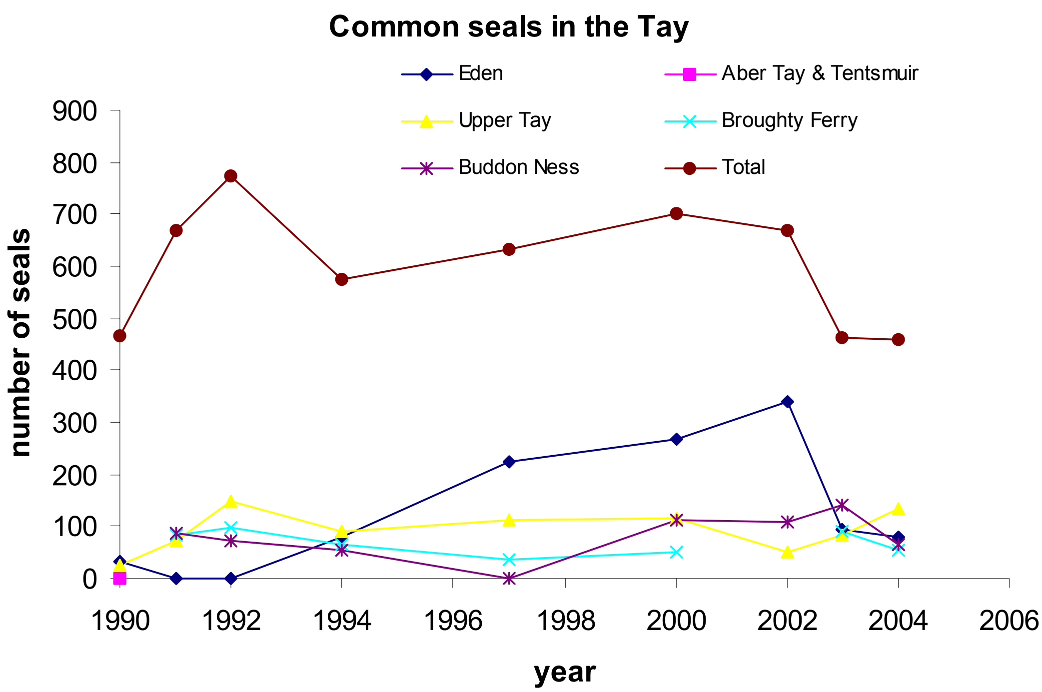


Table 1. Numbers of commons seals counted on the east coast of England since 1988. Data are from fixed-wing aerial surveys carried out during the August moult.

Date of survey	**13.8.88**	**8.8.89** **12.8.89**	**11.8. 1990**	**2.8.91** **11.8.91**	**1.8.92** **16.8.92**	**8.8. 1993**	**6.8.94** **12.8.94**	**5.8.95** **15.8.95**	**2.8. 1996**	**2.8.97** **8.8.97**	**7.8.98** **14.8.98**	**3.8.99** **13.8.99**	**4.8. 00** **12.8.00**	**4.8. 2001**	**11.8.02** **12.8.02**	**9.8.03** **10.8.03**	**6.8.04** **14.8.04**
Blakeney Point	701	- 307	73	- -	- 217	267	- 196	438 392	372	250 371	535 738	715 602	895 dist.	772	346 631	 399	577 715
The Wash	3087	1531 1580	1532	1226 1551	1724 1618	1759	2277 1745	2266 1902	2151	2561 2360	*2367 2381	2320 2474	2528 3029	3194	3037 2916	2529 2497	2126 2167
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
Scroby Sands	-	- -	-	- -	- -	-	61 -	- 49	51	58 72	52 -	69 74	84 9	75			49 64
The Tees	-	- -	-	- -	- -	-	- 35	- -	-	- -	- -	- -	- -	-	-		- -
Holy Island, Northumber-land	-	- -	-	- -	- -	-	- 13	- -	-	- 12	- -	- -	- 10	-	-		- -
Essex, Suffolk & Kent	-	- -	-	- -	- -	-	- -	90 -	-	- -	- -	- -	- -	-	- 72	 190	- -

*** One area used by common seals was missed on this flight (100 – 150 seals); this data point has been excluded from analyses**

Table 2. Numbers of common seals in the Moray Firth (SMRU surveys).

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
Ardersier	154		221	234	191	110	205	172	232
Beauly Firth	220		203	219	204	66	151	175	180
Cromarty Firth	41		95	95	38	42	113	90	86
Dornoch Firth (pSAC)	662		542	593	405	220	290	199	262
Inner Moray Firth Total	**1077**		**1061**	**1141**	**838**	**438**	**759**	**636**	**760**
Findhorn			*58*	*46*	*111*	*144*	*167*	*0*	*98*
Dornoch to Loch Fleet		*16*		*27*	*33*	*62*	*56*	*58*	*70*
Loch Fleet to Dunbeath		*92*		*214*		*145*			

*Note that the 1992 and 1994 Moray Firth Totals both include the data from 1993.

Table 3 . Numbers of common seals in the Firth of Tay.

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	10 Aug 2004
Eden Estuary	31	0	0	80	223	267	341	93	78
Abertay & Tentsmuir	409	428	456	289	262	153	167	53	126
Upper Tay	27	73	148	89	113	115	51	83	134
Broughty Ferry		83	97	64	35	52		90	55
Buddon Ness		86	72	53	0	113	109	142	66
Firth of Tay Total		**670**	**773**	**575**	**633**	**700**		**461***	**459**

* 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. Numbers of harbour seals in subsections of north west Skye

Location	4&6/8/88	05/08/89	08/08/90	07/08/91	04/08/92	10/08/93	03/08/96	02&05/07/00		06/08/0
								adults	pups	
Ascrib Islands	166	207	79	66	93	176	220	119	50	34
Isay group	114	88	95	78	84	128	126	52	21	12
Lampay	26	13	8	6	6	9	8	15	4	4
Inner Loch Dunvegan	314	289	211	155	97	314	302	269	152	46
Less **Dunvegan Village**	0	0	0	-26	-8	0	0	0	0	[illegible]
NW Skye pSAC	**620**	**597**	**393**	**279**	**272**	**627**	**656**	**455**	**227**	**96**
Skye Total	**1233**	**1269**			**1296**		**1728**			**224**

Table 4 (contd.). Numbers of harbour seals in subsections of north west Skye

Location	1 Aug 2004	2 Aug 2004	3 Aug 2004	4 Aug 2004	5 Aug 2004	6 Aug 2004
Ascrib Islands	190	205	212	210	232	257
Isay group	55	75	89	86	125	89
Lampay	58	71	67	94	81	76
Inner Loch Dunvegan	243	261	221	296	352	347
Less **Dunvegan Village**	0	0	0	0	0	0
NW Skye pSAC	**546**	**612**	**589**	**686**	**790**	**769**
Broadford		**273**	**190**	**192**	**289**	**303**
Kylerhea		**53**	**4**	**65**	**67**	**54**
Plockton		**217**	**146**	**199**	**350**	**279**
Greshornish Is	**37**	**101**	**49**	**98**	**103**	**91**

Table 5. Minimum estimates of the UK common seal population by region. Figures in bold type have been updated with data from surveys carried out in 2003

Region	Year of survey	1996-2004
Shetland	2001	4,883
Orkney	2001	7,752
Outer Hebrides	2003	2,098
Highland East & North (Nairn to Cape Wrath)	1997, 2004	**1,232**
Highland West (Cape Wrath to Appin, Loch Linnhe)	1996, 1997, 2000	4,947
Strathclyde West (Appin to Mull of Kintyre)	2000	6,918
Strathclyde, Firth of Clyde (Mull of Kintyre to Loch Ryan)	1996	991
Dumfries & Galloway (Loch Ryan to English Border at Carlisle)	1996	6
Grampian (Montrose to Nairn)	1997, 2004	**113**
Tayside (Newburgh to Montrose)	1997, 2004	**121**
Fife (Kincardine Bridge to Newburgh)	1997, 2004	**414**
Lothian (Torness Power Station to Kincardine Bridge)	1997	40
Borders (Berwick upon Tweed to Torness Power Station)	1997	0
TOTAL SCOTLAND		**29,515**
Blakeney Point	2004	**715**
The Wash	2004	**2167**
Donna Nook	2004	**346**
Scroby Sands	2001	64
Other east coast sites	1994, 2000, 2003	225
South and west England (estimated)		20
TOTAL ENGLAND		**3,537**
TOTAL BRITAIN		**33,052**
TOTAL NORTHERN IRELAND	2002	**1,248**
TOTAL BRITAIN & N. IRELAND		**34,300**
TOTAL REPUBLIC OF IRELAND	2003	**2,905**
TOTAL FOR GREAT BRITAIN AND IRELAND		**37,205**

Sharples, R. J., Cunningham, L. & Hammond P.S.

Distribution and movements of harbour seals around the UK

Sea Mammal Research Unit, Gatty Marine Laboratory, University of St Andrews, St Andrews KY16 8LB

Introduction

Recent satellite telemetry research, conducted at SMRU and in Denmark and the Netherlands, has highlighted that harbour seals can forage much further offshore than previously shown. As a result there has been further investment to identify the possible impacts that developments relating to the oil, gas and renewable energy industries may have on harbour seal foraging areas. Satellite telemetry data is also valuable in the context of considering the location and effectiveness of Special Areas of Conservation (SACs) for harbour seals under the EU Habitats Directive. The preliminary results described and discussed here compare data collected from harbour seals around the UK by SMRU to date, a total of 113 deployments.

Material and Methods

Satellite relay data loggers (SRDLs) were deployed on 10 harbour seals caught on Islay and Jura, 14 on Skye, 15 in Shetland, 15 in Orkney, 10 in the Moray Firth, 25 in St Andrews Bay and 24 in the Wash, between November 2001 and March 2005. Two deployments were made at each study site to improve data coverage over the year. The SRDLs were attached to the back of the neck behind the head using fast setting epoxy resin as described in Fedak *et al*. (1983).

Results

Individual tracks of all tagged seals are shown in *figure 1* and described below according to location.

Islay & Jura, southwest Scotland

A total of 1195 days of data have been collected from 10 harbour seals (5 females; 5 males) captured off southeast Islay and the east coast of Jura in September 2003 and April 2004.

The seals were site-faithful, repeatedly returning to within 2 km of the haul-out in the autumn/winter and within 5 km during the spring/summer months. The majority of movements consisted of repeated trips to within 10 km of the haul-out during the autumn/winter and within 20 km during the spring/summer. Longer distance movements (mean 55 km, maximum approximately 125 km) occurred when the seals changed haul-out site at the end of September, moving to haul-out sites on the Mull of Kintyre, Arran and Stranraer, and again at the end of March when they returned to Islay. Foraging trips averaged 0.9 days in duration and lasted an individual mean maximum of 4 days.

Isle of Skye, northwest Scotland

A total of 1828 days of data have been collected to date from 14 harbour seals (5 females; 9 males) captured off the northwest coast of the Isle of Skye (western Loch Dunvegan and the Isay Group) in September 2004 and March 2005.

The animals showed both repetitive short distance trips (around 15 km in the spring and 30 km in the autumn/winter) and longer distance movements (mean 85 km, maximum approximately 170 km). Seals travelling short distances repeatedly visited the same areas with no apparent seasonality. The longer distance movements occurred when a male made two return trips to Tiree, another male passed through the Sound of Barra before heading offshore and a female went to the east coast of Lewis and then moved to the Shiants. Foraging trips averaged 1.1 days in duration and lasted an individual mean maximum of 5 days.

Shetland

A total of 1990 days of data have been collected from 14 harbour seals (7 females; 7 males) captured in Yell Sound (North Shetland) and the south east coast of Shetland.

Animals captured in the north remained largely within the confines of Yell Sound with some further ranging movements. Three out of the 14 animals tracked made trips of more than 100 km from haul-outs. Animals tagged in the southeast of Shetland made repeated trips within 50 km from the haul-out. The majority of animals were site faithful in haul-out areas moving within 15 km of where they were caught. One animal moved to the island of Papa Stour, 70 km away to haul-out before returning to Yell Sound. Foraging trips averaged 1.7 days in duration and lasted an individual mean maximum of 8 days.

Orkney

A total of 2313 days of data have been collected from 16 harbour seals (9 females; 7 males) captured on Sanday and Stronsay (east Orkney) and Eynhallow and Rousay (west Orkney) in October 2003 and March 2004.

Animals tagged in the west appeared to be foraging in a concentrated area 30 to 40 km offshore from their haul-out area. Animals in the east of Orkney seemed to be foraging in all directions around the tagging area with slightly higher densities of locations obtained to the south. One female tagged on Sanday, Orkney, travelled repeatedly between Orkney and Shetland, a distance of over 220 km, hauling out in both island groups. An adult male caught in Orkney travelled approximately 75 km south, to the north coast of Scotland, again hauling out at both sites. Foraging trips averaged 1.5 days in duration and lasted an individual mean maximum of 6 days.

Moray Firth, northeast Scotland

Ten harbour seals (4 females; 6 males) were tagged in the Moray Firth on the north east coast of Scotland between October 2004 and March 2005; 1079 days of data have been collected.

The animals showed a large degree of individual variation with some animals making repetitive short distance trips to approximately 30 km while others were consistently travelling to over 70 km to forage. The majority of animals were site faithful in haul-out sites, with only one animal moving approximately 50 km to haul-out in the Beauly Firth. Foraging trips averaged 4.8 days in duration and lasted an individual mean maximum of 10 days.

St Andrews Bay, southeast Scotland

A total of 3800 days of data have been collected from southeast Scotland from 25 harbour seals (12 females; 13 males) captured in St Andrews Bay between November 2001 and July 2003.

Distances travelled ranged from 10 km to 120 km, with a mean of 46 km. These animals were site faithful, repeatedly returning to within 3 km of the haul-out site where they were tagged. No seals hauled out outside St Andrews Bay except one young male that travelled to Leith Docks where it remained for 3 weeks, and then to the docks in Newcastle-upon-Tyne where it remained for several months. Foraging trips averaged 4.6 days in duration and lasted an individual mean maximum of 12 days.

The Wash, eastern England

A total of 3271 days of data have been

collected from 24 harbour seals (13 females; 11 males) captured in The Wash between October 2003 and March 2005.

Seals tagged in The Wash tended to make repeated trips of relatively long distance and duration. With the exception of one animal that remained within 20 km of the haul-out, seals travelled repeatedly to between 75 and 120 km offshore and as far as 220 km to assumed foraging patches. Foraging trips averaged 8.3 days in duration and lasted an individual mean maximum of 16 days.

All seals tagged in The Wash were highly consistent in their individual foraging habits, repeatedly travelling to the same areas. No seasonality in behaviour was apparent. All but one of the seals tagged, which used a haul-out site 60 km north of The Wash, remained faithful to the haul-out site at which they were captured.

Discussion

The data sets presented here have vastly improved our knowledge of harbour seals in UK waters. Harbour seals have now been tracked in seven different areas around the UK and the data will provide a wealth of information on a number of aspects of their ecology as well as the offshore distribution of these populations.

The data collected here are being further analysed using a modelling framework developed at SMRU which predicts where seal populations spend their time at sea using additional information on the numbers of animals counted at haul-out sites throughout the area (Matthiopoulos, 2003 a, b; Matthiopoulos et al.*, 2004)*

Acknowledgements
Many thanks to all those who assisted with the fieldwork, to Mike Lonergan for help filtering the data, and to Scottish Natural Heritage, Geotech and DTI for funding.

References

1. Fedak, M. A., Anderson, S. S. and Curry, M. G. (1983). Attachment of a radio tag to the fur of seals. Journal of Zoology 200: 298-300.
2. Matthiopoulos, J. (2003a). The use of space by animals as a function of accessibility and preference. Ecological Modelling 159: 239-268.
3. Matthiopoulos, J. (2003b). Model-supervised kernel smoothing for the estimation of spatial usage. Oikos 102: 367-377.
4. Mathiopoulos, J., McConnell, B., Duck, C. and Fedak, M. (2004). Using telemetry and aerial counts to estimate space use by grey seals around the British Isles. Journal of Applied Ecology 41: 476-491.

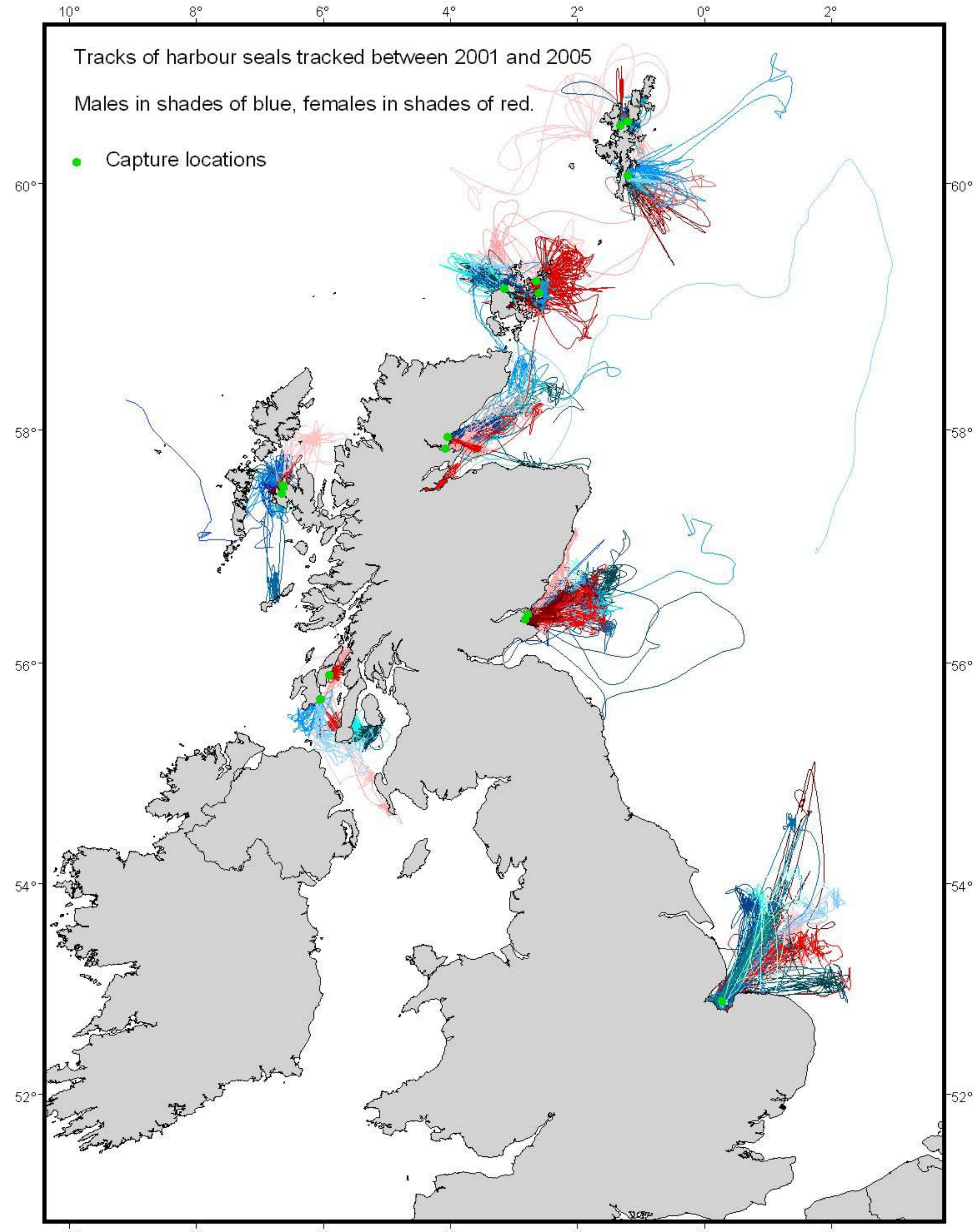


Figure 1: Individual tracks of all harbour seals captured on the Isles of Skye, Jura and Islay, Orkney, Shetland, the Moray Firth, St Andrews Bay and in The Wash.

I.M. Graham, R.N. Harris, C.D. Duck & I.L. Boyd

Current research being undertaken into seal-salmon interactions in freshwater in the Moray Firth

NERC Sea Mammal Research Unit, Gatty Marine Laboratory, University of St Andrews, St Andrews, KY16 8LB

Introduction

A research programme was initiated in January 2005 into seal-salmon interactions in freshwater in the Moray Firth. Results from the programme will help to inform future annual reviews of the Moray Firth Seal Management Plan, and seal-salmon conflicts nationally. The three main areas that the research programme is investigating are:

1. The use of non-lethal methods for the removal of seals from rivers.
2. Patterns of use of seals in rivers.
3. Impact of seals on salmonids.

Non-lethal Methods

Acoustic Deterrent Devices (ADDs) have been in use as anti-predator controls at marine salmon farms since the 1980s, but views on their effectiveness are equivocal (Quick, Middlemas & Armstrong, 2004). Our primary objective is to assess from a management perspective whether seals can be effectively deterred from specific areas of rivers by deploying an ADD?

An initial series of experiments is aimed at testing individual rather than population level responses to deployment of a commercially available ADD. Rather than deploy an ADD in a permanent, or even semi-permanent, situation, it will be deployed simply for the duration of each experiment. Individual seals located in rivers will be exposed to noise from an ADD for a period of 10 minutes and their behaviour recorded before, during and after exposure to the ADD. In control situations, the ADD will be deployed in the river but not turned on. Response to the ADD will be measured by observing the position, orientation and activity of seals in relation to the sound source when switched on and off using a video camera.

Seals in Rivers: Patterns of Use

More detailed information on the patterns of use of rivers by seals would help to inform the choice of appropriate management strategies for seal and salmon interactions (see for example Graham *et al.*, 2005).

This work aims to address the following questions:

1. What is the spatial and temporal distribution of seals in rivers in the Moray Firth?
2. Do individual seals specialise in using rivers?
3. What are the movements of seals involved in salmon predation, and do they differ from the population as a whole?

To determine the frequency and pattern of occurrence of seals in rivers we have established a programme of standardised surveys on three rivers in the Moray Firth: the Rivers Ness, Conon and Kyle of Sutherland. From March 2005, a minimum of four surveys has been conducted on each river each month. Surveys are carried out before 12 noon and within three hours of high tide. Comparable standardised counts of seals have been carried out on the River Spey by the Spey DSFB since January 2004 (Butler, 2004). In addition, salmon fishery managers are recording incidental sightings of seals in rivers to give a qualitative overview of seal occurrence in rivers and in particular to determine the spatial and temporal distribution of seals above the normal tidal limits in rivers. This work will allow suitable opportunities and locations for photographing and catching seals and for testing ADDs to be identified.

The use of rivers by seals will be further investigated using a combination of three techniques:

1. Photo-identification. Individual seals can be identified on the basis of their pelage pattern, although this technique may be more successful for grey seals than harbour seals, since grey seal pelage is more legible. Seals observed in rivers during the course of surveys, and opportunistically, are being photographed to determine whether or not specific individuals are repeatedly using rivers. The success of this method will depend on obtaining photographs of sufficient quality and resolution to distinguish individual pelage markings.

2. Satellite tracking. By capturing seals in rivers and fitting them with telemetry tags we will be able to determine their movements and establish whether or not these individuals are specialising in using rivers. We are currently investigating suitable opportunities to capture individual seals in rivers. It is planned to deploy Argos satellite relay data loggers (SRDL) on individual seals. However, SMRU is currently developing a telemetry tag that utilises a GPS location-fixing system, Fastloc/GSM. These tags will be accurate to within 50m and will be more suitable for studying the fine scale movements of seals in rivers. If they are available Fastloc/GSM tags will be deployed in preference to SRDL tags.

3. Fatty acid composition/stable isotope ratios. The fatty acid composition and stable isotope ratios of carbon and nitrogen in animal tissue are ultimately related to diet and are expected to differ between populations of animals that feed in a freshwater or in the marine environment. On the basis of their stable-carbon isotope ratios, seals from a population in Canada that have access to both the freshwater and the marine environment have been successfully distinguished from seals that are resident year-round in freshwater, and from seals that are resident entirely in the sea (Smith *et al.*, 1996). The fatty acid composition and stable isotope ratios of seals shot in rivers will be compared with those obtained from seals in the marine environment to see if they can be distinguished. This will be dependent on recovering a sufficient number of carcasses of seals shot in rivers. The species, sex and age of seals shot will also be determined from recovered carcasses.

Impact of Seals on Salmonids

The theoretical impact of removing seal predation from salmon rivers was investigated in a collaborative study. The results of the model provide useful guidance for a targeted approach to seal management (see Graham *et al.* 2005). It is however difficult to directly quantify empirically the level of salmonid mortality that is attributable to seals. The prevalence of damage on rod-caught salmon and sea trout may provide some relative indication of the seasonal rate of seal predation on salmonids: for example the percentage of damaged salmon caught by three fisheries on the River Spey in 2004 was positively correlated with the presence of seals in the lower Spey with a 1-month lag (Butler, 2004). A scheme to record damage on rod-caught salmonids has been established on selected fisheries on eight rivers in the Moray Firth. Fisheries managers have been issued with cameras to photograph damaged fish and notebooks to record information on these fish and the number checked for damage. It is hoped to relate the levels of damage to the abundance of seals within individual rivers where this information is available. The success of this scheme will be reviewed at the end of the 2005 fishing season.

The short and longer-term diet of seals shot in rivers will be studied from the carcasses of seals shot in rivers. Stomach contents will be used to determine the short-term diet of seals in rivers. Fatty acid composition and stable isotope ratios will give a qualitative assessment of the diet over a longer time period.

Acknowledgements

This study is funded by the Scottish Executive and a private charitable donation.

References

Butler, J.R.A. (2004) *Moray Firth Seal Management Plan; a Pilot Project for Managing Interactions Between Seals and Salmon in Scotland.* Spey Fishery Board, Aberlour, Morayshire, UK.

Graham, I.M., Middlemas, S.J., Butler, J.R.A., Thompson, P.M., & Armstrong, J.D. (2005). The Potential Impact Of Removing Seal Predation From Atlantic Salmon Rivers: The Relevance Of Salmon Population Scale. ***SCOS Briefing Paper*** 05/9**.**

Quick, N.J., Middlemas, S.J., & Armstrong, J.D. (2004) A survey of antipredator controls at marine salmon farms in Scotland. *Aquaculture*, **230**, 169-180.

Smith, R.J., Hobson, K.A., Koopman, H.N., & Lavigne, D.M. (1996) Distinguishing between populations of fresh- and salt-water harbour seals (*Phoca vitulina*) using stable-isotope ratios and fatty acid profiles. *Canadian Journal of Fisheries and Aquatic Sciences*, **53**, 272-279.

Cunningham, L. & Duck, C.

Population assessment methods of harbour seals

Sea Mammal Research Unit, Gatty Marine Laboratory, University of St Andrews, St Andrews KY16 8LB

Summary

Harbour seals on the west coast of Scotland show intra-annual fidelity to haul-out sites, with the majority of their movements occurring within 30 km of the haul-out. A generic coefficient of variation (15%) was defined from repeat aerial surveys to allow comparison between future harbour seal counts. Predictions from a generalised additive model of repeat land-based counts of harbour seals suggest that the timing of the current SMRU aerial survey window may either be too early, too wide or both. Photo-identification of harbour seals may provide an additional or alternative population assessment method.

Introduction

The European Habitat's Directive protects harbour seals (*Phoca vitulina*) in Special Areas of Conservation (SAC). The Directive requires populations within these SACs to be monitored with a six-yearly reporting cycle.

The Sea Mammal Research Unit (SMRU) has carried out aerial surveys of harbour seals around the British coast since 1988. Counting methods are designed to reduce the potential effects that date, time of day, tide and weather might have on population estimates. For consistency, these aerial counts are only carried out during a three-week survey window within the annual moult when, in most areas, greatest numbers of seals are hauled ashore (Thompson & Harwood, 1990; Boveng *et al.*, 2003; Harris, Lelli & Gupta, 2003). Repeat land and aerial counts were used to examine whether seal numbers reach a plateau during the survey window, in order for long-term trends to be determined from surveys.

Temporal and financial limitations restrict the frequency of aerial counts, such that each area of coast is surveyed on average once every four to five years. To understand more about the conservation status of harbour seals, mark-recapture could be used as an additional or alternative monitoring technique. Harbour seals have unique pelage patterns that provide the potential for individual photo-identification from natural markings. As well as providing local abundance estimates, photo-identification could provide additional information on estimating adult and pup survival, distribution and the general health status of individuals.

Both direct counts and photographic surveys of harbour seals assume that animals are only counted once. Several studies suggest that harbour seals show site-fidelity (Anderson, 1981; Yochem *et al.*, 1987; Thompson, 1989; Härkönen & Harding, 2001) but use different haul-out sites throughout the year (Brown & Mate, 1983; Thompson, 1989; Thompson *et al.*, 1996; Simpkins *et al.*, 2003). Thus satellite telemetry was used to determine whether harbour seals on the west coast of Scotland show site-faithfulness, returning to the same haul-out site, and if there is seasonal variation in the haul-out sites used throughout the year.

Material and Methods

Harbour seals on the southeast and northwest coasts of Skye were counted on five consecutive days during the 2004 summer moult using a thermal imaging camera mounted in a helicopter. Surveys were conducted within a four-hour window, two hours either side of low tide, in order to coincide with highest numbers of seals hauled out. In addition, harbour seals hauled out in southeast Skye were repeatedly counted from the land between May and September 2004.

Harbour seals in part of the northwest Skye SAC (approximately 0.5 km^2) were photographed each month between April and October 2005 from small tourist boats. Each seal was photographed several times from both sides and at different angles. Using computer-assisted matching, different pattern cells or combinations of pattern cells (ventral, flank, shoulder and side of head) were used for automatic selection of potential matching pairs and those pairs were then checked visually.

Satellite relay data loggers (SRDLs) were attached to the back of the neck of harbour seals caught in SACs between September 2003 and April 2005 using fast-setting epoxy resin (as described in Fedak *et al*. 1983). Ten SRDLs were deployed in southwest Scotland (Islay and Jura) and 14 in northwest Scotland (Isle of Skye).

Results

Repeat Counts

A generalised additive model (GAM) of repeat land-based counts showed two peaks in seal numbers during the period of May to September; highest counts were obtained during the pupping season in May and then declined before a second peak during the August moult (figure 1). This second peak occurred within the SMRU aerial survey window, but predicted numbers of seals at the start and end of the survey window were lower than at the peak's zenith on 15th August. The shape of the peak further suggests that the SMRU survey window may either start too early or be too broad. Few counts were done in September and so the effect of late season on seal counts is imprecise.

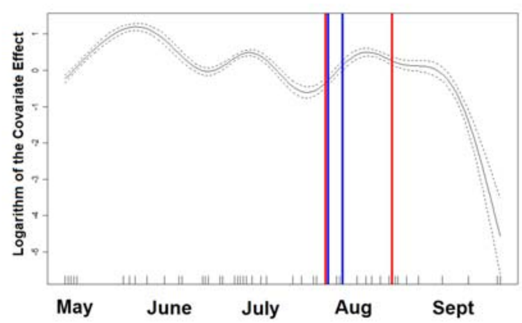


Figure 1: The effect of date, a smooth term component of the GAM, for land-based counts of harbour seals in southeast Skye. Upper and lower curves represent approximate 95% confidence intervals. Red lines represent the start and finish of the SMRU survey window and blue lines show the start and finish of the five consecutive repeat aerial counts.

As predicted by the GAM, seal abundance did not remain stable during the five repeat aerial surveys conducted at the beginning of the SMRU survey window. Counts increased significantly between the start and finish of the study period (2nd - 6th August, Wilcoxon $Z= -1.99$, $p = 0.046$), and there was also a significant increase between 3rd - 4th and 4th - 5th August ($Z= -1.99$, $p = 0.046$ and $Z= -2.20$, $p = 0.028$ respectively). The coefficient of variation (CV) of the repeat aerial counts was approximately 15% of the mean count and ranged widely among sub-regions, from less than 5% to over 26%.

Photo-Identification

Approximately 700 photographs were taken each month to test the use of computer-assisted photo-identification for estimating harbour seal abundance. Although matching is still in progress, over 50 individuals have been recaptured so far, with a further 170 individuals seen only once.

Satellite Telemetry

Harbour seals caught in SACs on the west coast of Scotland were site-faithful, repeatedly returning to within 5 km of the haul-out. A third of tagged seals used two or three different haul-out areas repeatedly, with seals caught on Islay appearing to show seasonal preferences for haul-out sites (figure 2 and SCOS Briefing Paper 05/10).

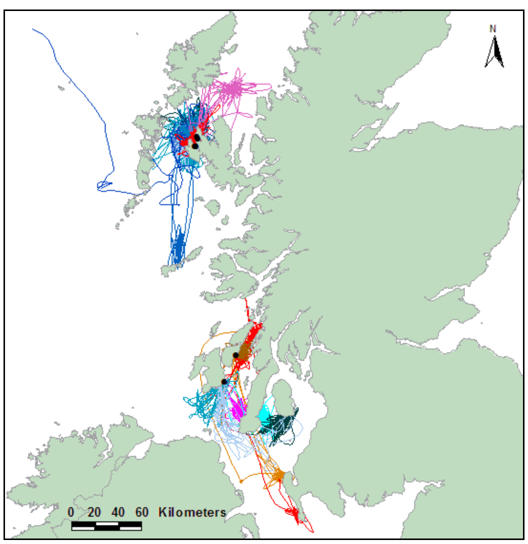


Figure 2: Individual tracks of males (shades of blue) and females (shades of red) tagged off the Isles of Skye, Islay and Jura (capture locations illustrated with black dots).

Discussion

The principal assumptions for estimating minimum harbour seal numbers during the moult are that animals are only counted once and that the survey window fits a period when variation is minimised, with no significant trend in abundance. Satellite telemetry confirms that harbour seals on the west coast of Scotland are faithful to a home haul-out site, with some individuals changing home haul-out site once or twice during the duration of the tagging period (mean 126 days, maximum 253 days). However this study showed that numbers of seals hauled out around the Isle of Skye may still be increasing at the start of the SMRU survey window. In order to improve the 15% error on either side of the mean, this survey window may need to be redefined, or the consequences of not doing so re-examined. This preliminary result is based only on data from one location in one year, and so further work should look at the effect of spatial and temporal variation.

The photo-identification data have yet to be analysed, but matches both between and within surveys strongly suggest that the method will prove a successful monitoring tool and could be expanded to provide a larger scale assessment method of the harbour seal population.

Acknowledgements

Many thanks to all those who assisted with the fieldwork, particularly Simon Moss, to Mike Lonergan for all his patient statistical advice, to Lex Hiby for developing the semi-automated photo-identification program, and to Macleod Estates for the use of their boats and boatmen. Thanks also to Scottish Natural Heritage and the Wester Ross Fisheries Trust for funding.

References

Anderson, S.S. (1981) Seals in Shetland waters. *Proceedings of the Royal Society of Edinburgh*, **80B**, 181-188.

Boveng, P.L., Bengtson, J.L., Withrow, D.E., Cesarone, J.C., Simpkins, M.A., Frost, K.J., & Burns, J.J. (2003) The abundance of harbor seals in the Gulf of Alaska. *Marine Mammal Science*, **19**, 111-127.

Brown, R.F. & Mate, B.R. (1983) Abundance, movements and feeding habits of harbor seals (*Phoca vitulina*) at Netarts and Tillamook Bays, Oregon. *Fishery Bulletin*, **81**, 291-301.

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

Harris, D.E., Lelli, B., & Gupta, S. (2003) Long-term observations of a harbor seal haul-out site in a protected cove in Casco Bay, Gulf of Maine. *Northeastern Naturalist*, **10**, 141-148.

Simpkins, M.A., Withrow, D.E., Cesarone, J.C., & Boveng, P.L. (2003) Stability in the proportion of harbor seals hauled out under locally ideal conditions. *Marine Mammal Science*, **19**, 791-805.

Thompson, P.M. (1989) Seasonal changes in the distribution and composition of common seal *Phoca vitulina* haul-out groups. *Journal of Zoology (London)*, **217**, 281-294.

Thompson, P.M. & Harwood, J. (1990) Methods for estimating the population size of common seals (*Phoca vitulina*). *Journal of Applied Ecology*, **27**, 924-938.

Thompson, P.M., McConnell, B.J., Tollit, D.J., Mackay, A., Hunter, C., & Racey, P.A. (1996) Comparative distribution, movements and diet of harbour and grey seals from the Moray Firth, N.E. Scotland. *Journal of Applied Ecology*, **33**, 1572-1584.

Yochem, P.K., Stewart, B.S., DeLong, R.L., & DeMaster, D.P. (1987) Diel haul-out patterns and site fidelity of harbour seals (*Phoca vitulina richardsi)* on San Miguel island, California in Autumn. *Marine Mammal Science*, **3**, 323-332.

C.D. Duck, B.L. Mackey and J. Matthiopoulos

Defining management areas for seals in Scotland

NERC Sea Mammal Research Unit, Gatty Marine Laboratory, University of St Andrews, St Andrews KY16 8LB

The problem

In order to establish management areas for seals, some knowledge of their distribution within the area is required. However, seals are highly mobile and their distribution is likely to change over a period of time. Movements may be frequent, seasonal or take place over a longer time period, perhaps in response to changes in prey distribution or the availability of suitable terrestrial habitat (such as haulout and/or breeding sites).

Given seals' potential to move, the selection of boundaries between management areas will, necessarily, be arbitrary. Ideally, all seals within one area would remain within that area and there would be little or no exchange of seals across boundaries. Inevitably, there will be movement across boundaries and more movement across some than others. Selection of boundaries will be a compromise between minimising seal movement and limiting the size of the management areas.

The placement of area boundaries will also be dependent on the requirements of the proposed management regime.

Seal distribution

The distribution (at 10km resolution) of common seals in Scotland is shown in Figure 1. This plot shows common seal distribution at only one time of year, in August, when the seals are moulting. From telemetry studies, we know that in winter, common seals spend longer at sea and less time ashore than in the summer (Sharples 2005, Sharples & Cunningham 2005) and, at certain locations, their winter and summer terrestrial distribution can be quite different (Sharples & Cunningham 2005). We do not know the winter distribution of common seals across the whole of Scotland.

The summer distribution of grey seals, determined from the summer surveys of common seals, is shown in Figure 2. The number of grey seals at a haulout site during the summer can vary greatly from day to day, so these data must be interpreted with caution. Note that grey seal summer distribution does not fit as neatly into the proposed areas outlined. Furthermore, telemetry studies show that, in general, grey seals move considerably more widely than common seals (McConnell *et al.* 1994). During the autumn, grey seals return to traditional colonies to breed and their distribution is quite different from their distribution in summer (Figure 3). We do not know the pattern of their winter distribution.

What are the existing management units?

There are currently four different management units for seals in Scotland. These vary considerably in scale and are:

1. ICES boxes (offshore) – for fisheries
2. SAC, SSSI – for seal conservation
3. District Salmon Fisheries Boards – for seals in or close to local river systems
4. Moray Firth Management Plan – for seal/salmon interactions in Moray Firth rivers.

Off shore, ICES boxes are used for fisheries management purposes and are the largest unit which maybe applied to Scottish seals (Figure 4), the whole Scottish coast, with all island groups, are covered by four ICES boxes. Since these areas are heavily used in fisheries management, they will be important when considering seal diet and foraging distribution. However, the areas may be slightly too large in relation to practical seal management in Scotland. Note that some of these areas include sections of the English, Welsh and Irish coasts. The ICES boxes surrounding Scotland are:

IVb Humber to Peterhead

IVa	Peterhead to Strathy Point, including Orkney and Shetland
VIa	Strathy Point to Loch Ryan, including the north and north-west coast of Ireland
VIIa	Loch Ryan to Pembroke, including the east coast of Ireland

Scottish Natural Heritage (SNH) has defined small management areas for both common and grey seals. For UK conservation objectives, Sites of Scientific Interest (SSSIs) were defined and more recently, for European Union conservation objectives, Special Areas of Conservation (SACs) have been identified in collaboration with the Sea Mammal Research Unit (SMRU). These exist for both common (nine) and grey seals (six). Although the SACs cover quite small areas, they are considered sufficiently large to satisfy the appropriate management requirements and are to be considered in conjunction with areas of coast immediately adjacent to the SAC (Figures 1 and 2). The locations selected for grey seal SSSIs and SACs were based on areas used during their autumn breeding season. Grey seals return to breed at traditional colonies which are fairly easily identified (Figure 3).

Many District Salmon Fisheries Boards apply to the Scottish Executive for licences to shoot seals during their respective close seasons. Most Boards apply for licences independently and, until recently, there has been little consideration of the overall effects on local seal populations.

In 2004, a larger management area in the Moray Firth was defined in an attempt to coordinate the seal management regimes of all the District Salmon Fisheries Boards around the Moray Firth (Butler 2004). This scheme aims to coordinate the management of seals over the whole of the Moray Firth and considers the effects of 'managing' seals in specific areas (i.e. salmon rivers) on the more widely dispersed local population.

Proposed seal management units for Scotland

A proposed subdivision of the coast of Scotland (see Figure 1), using a combination of district boundaries and apparently natural discontinuities in the distribution of main haulout sites and breeding colonies is:

1. Forth, Tay, Dee and Don	Berwick border to Rattray Head
2. Outer Moray Firth	Rattray Head to Duncansby Head
3. Shetland	Including Fair Isle and Foula
4. Orkney	Including Stroma and Duncansby Head to Dunnet Head
5. Far North-west	Dunnet Head to Rubha Reidh (west of Loch Ewe)
6. Western Isles	Including North Rona, Flannans, St Kilda and Shiants
7. West Highland	Rubha Reidh to Ardnamurchan Point, including Skye and Small Isles
8. S Highland and Argyll	Ardnamurchan to Machrihanish, including all Argyll islands
9. Clyde and Solway	Machrihanish to Silloth

These areas are outlined in Figures 1 to 3.

Although it is important that, once decided upon, management units remain unchanged, initial plans for subdivision should remain flexible until sufficient stakeholder and scientific input have been received. This will increase the ease and efficiency with which management is conducted. In particular, the aim should be to ensure that units are as independent of each other as possible so that management decisions can be made about one without severely influencing the others. This can be achieved by a) enclosing local stakeholders within single units and b) including strongly linked seal subpopulations in the same units. The rate of movement of individuals between subpopulations can be used to define the connectivity between them. SMRU has done preliminary work in this area that has provided some evidence for geographical isolation. In 2005, SMRU allocated one of its NERC PhD studentships to the continuation of this work and we will be reporting incrementally on new results over the next three years. The applied objectives of this new project are:

1) to find the spatial configuration of a predefined number of approximately independent management units and
2) to find the spatial configuration of an arbitrary number of approximately independent management units with a predetermined degree of connectivity.

References

Butler, J.R.A. 2004. Moray Firth Seal Management Plan. A pilot project for managing interactions between seals and salmon in Scotland. Unpublished Report.

McConnell, B. J., Fedak M. A., *et al*. (1999). Movements and foraging areas of grey seals in the North Sea. Journal of Applied Ecology **36**: 573-590.

Sharples R.J. 2005. Ecology of harbour seals in southeastern Scotland. Unpublished PhD thesis, University of St Andrews, Scotland.

Sharples R.J., Cunningham L. & Hammond P.S. 2005. Distribution and movements of harbour seals around the UK. SCOS Briefing paper 05/8.

Figure 1. The distribution of common seals in August, by 10km squares.

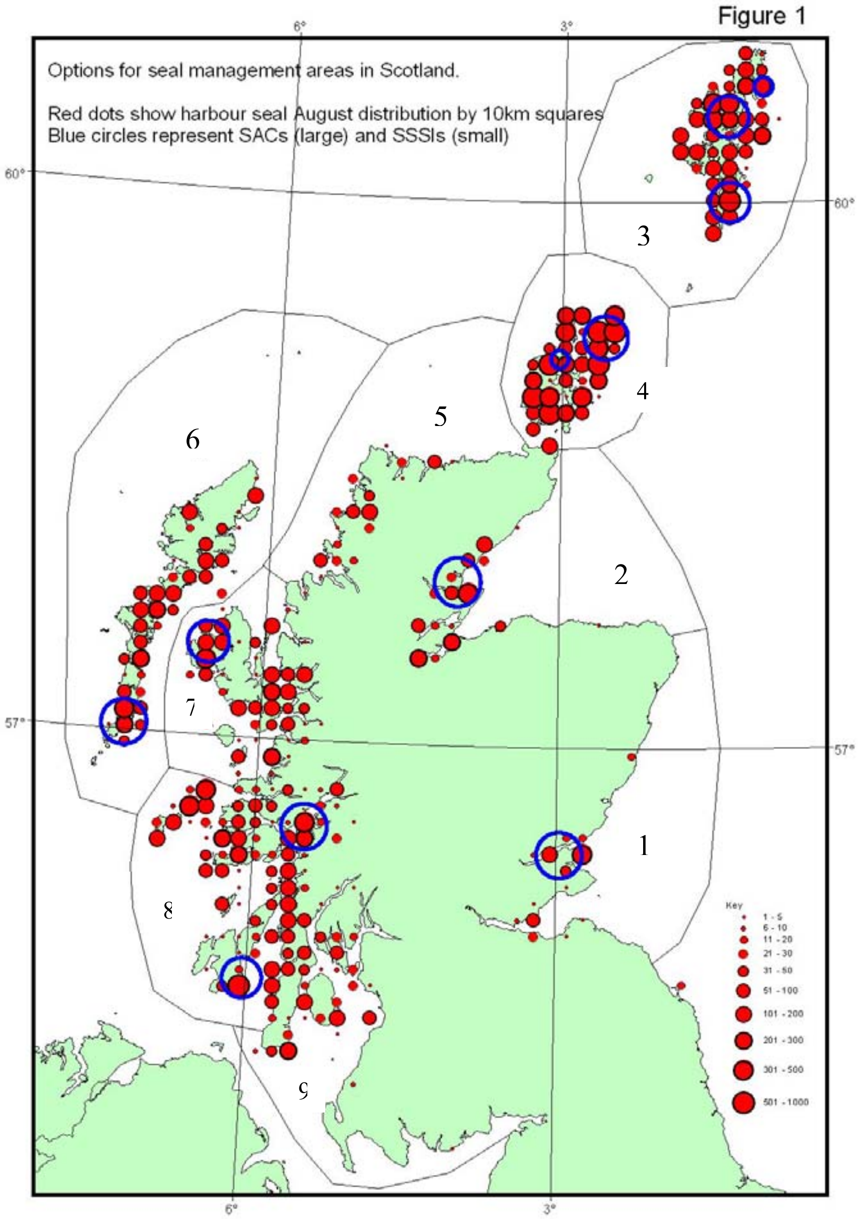


Figure 2. The distribution of grey seals in August, by 10km squares.

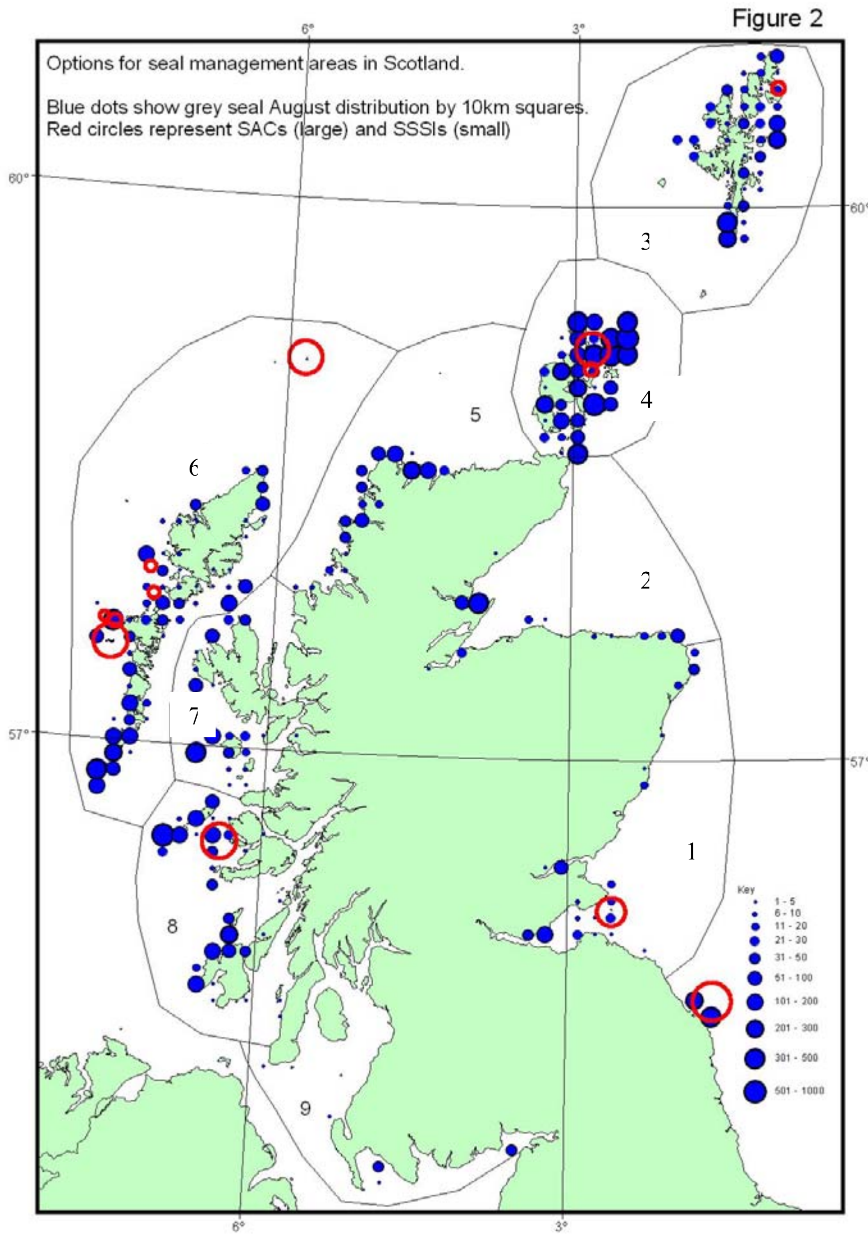


Figure 3. The distribution of grey seal breeding colonies in Scotland.

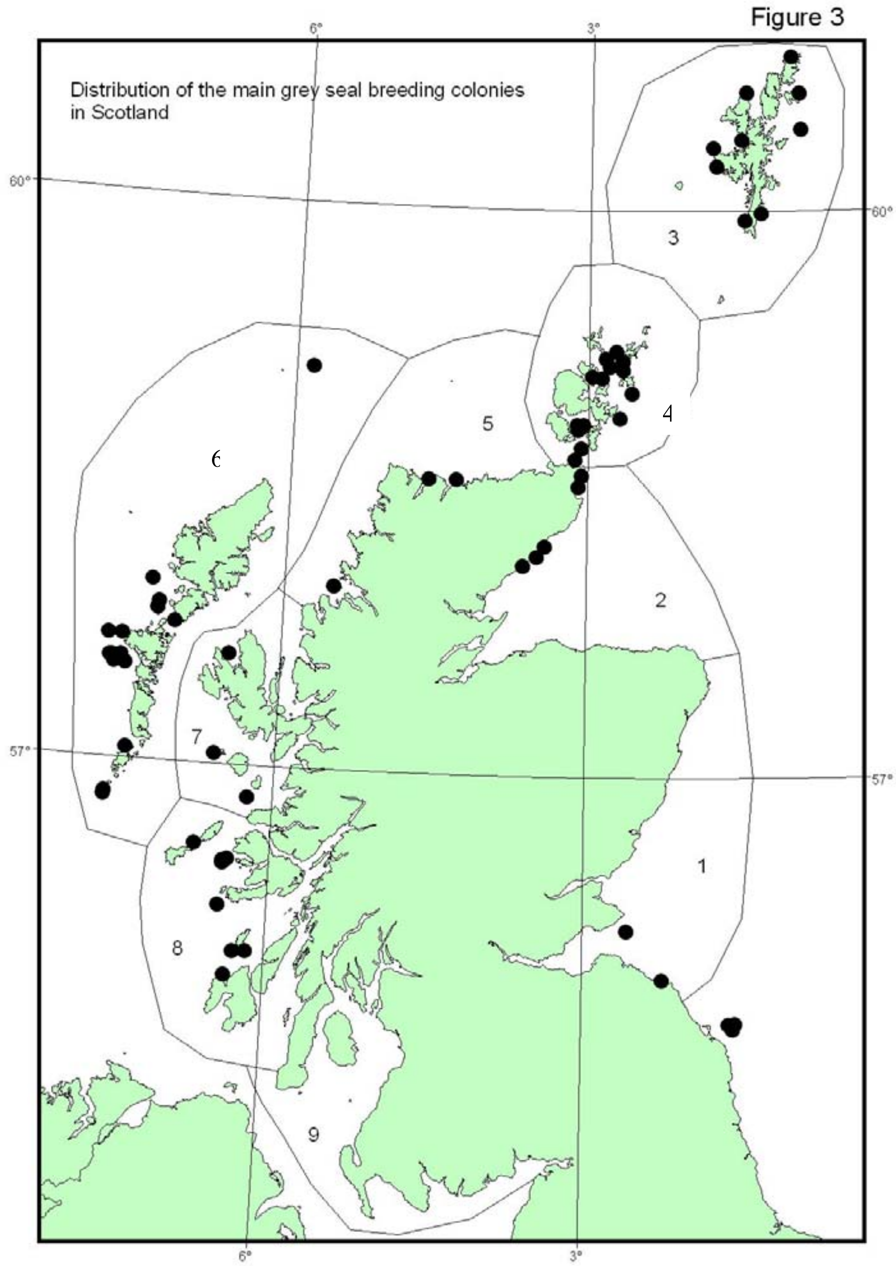
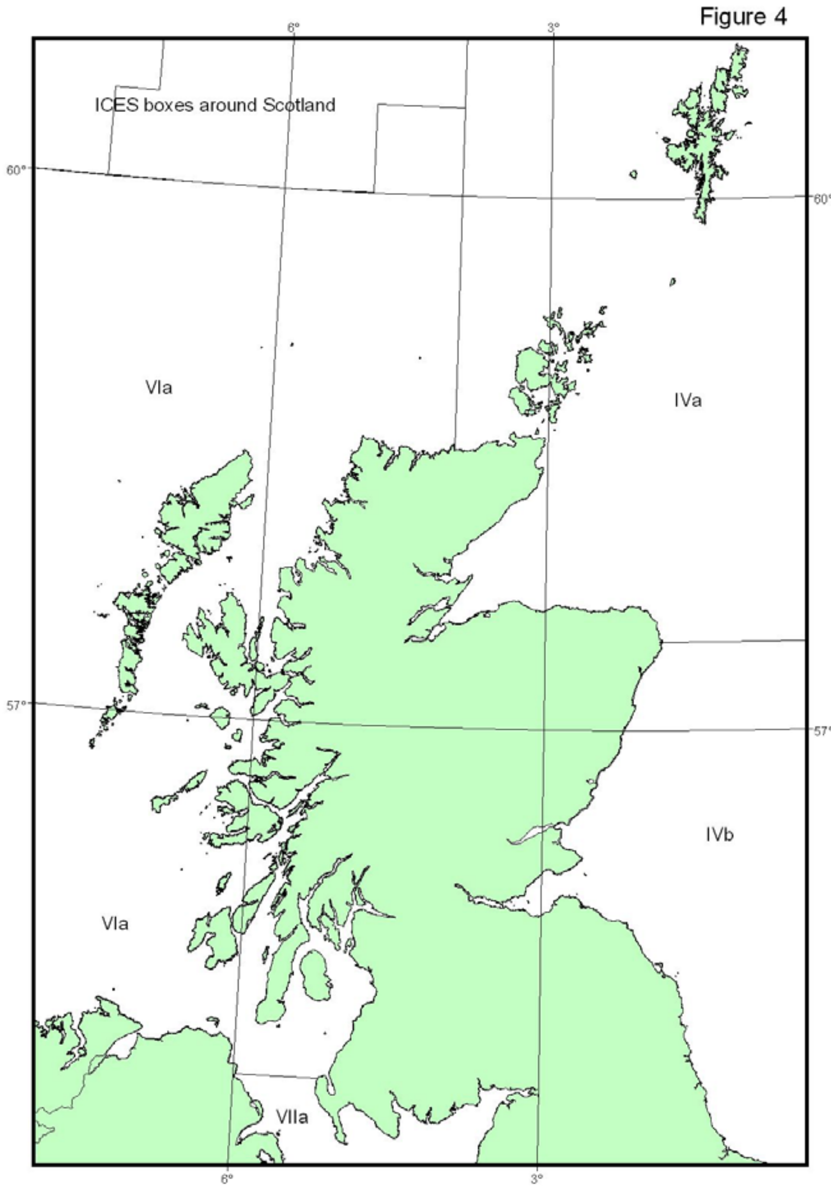


Figure 4. The location of ICES boxes surrounding Scotland.



SMRU uses two methods for surveying common seals, one using trend sites and another using helicopter-based surveys for regions in which low intensity monitoring is required. Work is ongoing to provide estimates of confidence in the helicopter-based surveys and to allow estimation of the total population size based on all survey methods.

I.M. Graham[1], S.J. Middlemas[2], J.R.A. Butler[3], P.M. Thompson[4] and J.D. Armstrong[2]

The Potential Impact Of Removing Seal Predation From Atlantic Salmon Rivers: The Relevance Of Salmon Population Scale

1. NERC Sea Mammal Research Unit, Gatty Marine Laboratory, University of St Andrews, St Andrews, KY16 8LB
2. Fisheries Research Services Freshwater Laboratory, Faskally, Pitlochry, PH16 5LB
3. Spey Fishery Board Research Office, 1 Nether Borlum, Knockando, Aberlour, AB38 7SD
4. University of Aberdeen, School of Biological Sciences, Lighthouse Field Station, Cromarty, Rossshire, IV11 8YJ.

Summary

In this paper we examine the potential impact on salmon stocks and rod fisheries of removing seals from three rivers in the Moray Firth. Removing seals is predicted to have a negligible impact when the number of salmon returning to a river is large, for example on the Spey during the summer. The model predicts the greatest potential impact when salmon numbers are low, for example on a small river or during the spring. The results of the model should only be considered as indicative rather than quantitative predictions, but they do provide useful guidance for a targeted approach to seal management.

Introduction

Managers of Atlantic salmon (*Salmo salar*) are particularly concerned with identifying actions that protect or increase the fish stocks that support fisheries. This concern has been accentuated in recent years by the widespread decline in stocks of Atlantic salmon. Although many believe that the cause(s) of the decline are primarily in the marine environment (e.g. Friedland *et al*., 2000), practical management has focussed on the coastal and freshwater environment, including the management of predators (Hilton *et al.* 2001). However the management of predators is particularly challenging when both predator and prey populations are protected and/or declining. Such is the case in the UK where both Atlantic salmon and grey (*Halichoerus grypus*) and harbour (*Phoca vitulina*) seals, are protected by Special Areas of Conservation (SACs) under the European Commission Habitats Directive (Council Directive 92.43/EEC).

We examine the potential effects on stocks and rod fisheries of removing seals from three rivers of different sizes in the Moray Firth region of Scotland. In addition we consider within-year variation in predation levels, fisheries and abundance of the sub-stocks that support those fisheries. The advantage of this approach is that it is possible to identify those situations in which losses to seals are sufficiently small that the costs of managing the seals exceed the benefits.

Material and Methods

The number of salmon consumed by seals in rivers was calculated using a bioenergetic approach. It was assumed that seals in rivers obtained their daily energy requirement solely from returning adult salmon. Seal consumption was calculated as:

$$s = \frac{N.C.D}{\varepsilon_c}$$

where s = the number of salmon consumed by seals, N is the average number of seals present daily in the river, C is the *per capita* daily energy requirement of a harbour seal (14689 KJ; Olesiuk, 1993), D is the time period in days and ε_c is the average energy content of an individual salmon of average weight.

To model the potential benefit of removing seals from rivers we assumed that fish released from seal predation were as likely to be captured in rod fisheries as those from the wider population. We also assumed that once removed from rivers seals were not replaced by conspecifics. Under these assumptions the theoretical cumulative increase in stock size and catch was calculated using information on the exploitation rate by rod fisheries:

$$i_j = \frac{\sum_{j=1}^{J} s_j}{\left(\sum_{j=1}^{J} f_j\right) \div E} \times 100$$

where i_j = the percentage increase in cumulative catch or stock at month j, E = the exploitation rate, f = the number of salmon caught by the fishery and

J = the total number of months in the sample. Since stock size is estimated from the rod catch the results reflect an increase in both the stock and catch. The cumulative increase in catch was calculated at monthly intervals in order to examine temporal trends in the predicted values of i.

We applied the model to three rivers of different sizes in the Moray Firth region: the Spey (large), Conon (medium) and Moriston (small; a tributary of the Loch Ness/River Ness catchment). Seal consumption was calculated using river-specific values for the average energy content of an individual salmon and the number of seals present (Table 1), assuming that all seals were harbour seals. For the Moriston, Williamson (1988) reports that an average of one seal enters Loch Ness every two years, and for the purposes of the model we assumed that one seal was continually present in the freshwater estuary of the Moriston. We calculated the potential effect of removing in-river predation by seals during the fishing season for the Spey (February – September) and the Moriston (January – May) and for the period for which seal presence data was available for the Conon (April – September). Although fishing did not take place during January in the Spey we assumed that fish released from seal predation in this month would be available to anglers during the season.

The average energy content of a salmon was calculated using the average weights (kg) of fish caught on each river, assuming that catches were representative of the total stock present, and an energetic density of 5933 KJ kg^{-1} (Tollit 1996). For the Spey and the Conon, monthly catch data were used from the same periods that the seal data were collected (Conon 1999-2000; Spey 2004). For the Moriston we used the average monthly catches for the period 2000-2004. The exploitation rate of the rod fisheries was taken to be 0.15, based on contemporary rates for the River Spey as calculated from comparison of acoustic counter and rod catch data (Butler, 2005). Values of i were calculated for each river to examine the potential effects of removing all seals present throughout the fishing season.

Table 1. *Mean number of seals present daily by month in the River Spey 2004 (Butler 2004) and the River Conon 1999-2000 (Middlemas 2003). The monthly presence of seals for the River Moriston was derived from Williamson (1988) (see text).*

Month	Spey	Conon	Moriston
Jan	2.8	-	1
Feb	0.5	-	1
Mar	1.4	-	1
Apr	0.4	0.2	1
May	0.3	0	1
June	0.3	0.2	-
July	0.1	0.7	-
Aug	1.2	0.2	-
Sept	1.1	0	-

Results

The potential increase in salmon stocks and catches varied greatly between the three rivers depending on their size (Figure 1). On the smallest river, the Moriston, the value of i was greatest (128%) in January, when sub-stocks of spring salmon are at their lowest abundance. As the number of spring salmon caught increased from February – May, the benefits of removing seal predation decrease.

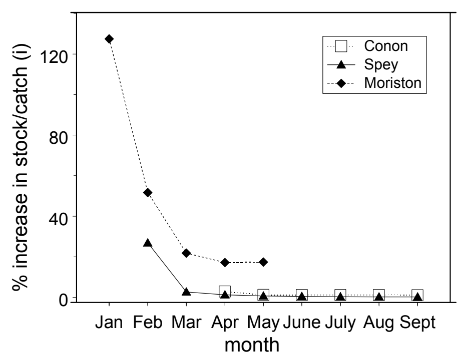


Figure 1. *The predicted cumulative increase in stock and rod catch (i) for the Spey, Conon and Moriston as a result of removing observed monthly numbers of seals. See Table 1 for mean daily presence of seals, and text for details of the model and associated assumptions.*

Similar trends were evident for the Spey in February – March, where a fishery exists for small numbers of spring salmon, but were not determined for the Conon, which does not support early season fishing (Figure 1).

The potential cumulative increase in salmon stocks and catches for the whole fishing season similarly varied with the size of the river. The cumulative annual value of i was greatest (17%) for the Moriston, as the smallest river with a total rod catch of 68, intermediate (1%) for the Conon, with a total rod catch of 479, and lowest (0.2%) for the Spey, as the largest river with a total rod catch of 9819.

Discussion

By calculating the theoretical impact of seals in terms of their consumption of salmon we can identify with a degree of certainty those situations where the impact of seal predation on salmon stocks may be minimal. Our model shows that in larger rivers such as the Spey and Conon, seals consume ≤1% of the total stock of salmon from April through to September. However, for smaller rivers, such as the Moriston, even a single seal could potentially remove 20% of the salmon stock from January to May. Although the available data was limited, the number of seals present varied little between rivers, indicating that the impact of seal predation would be greatest on small stocks of salmon.

Our findings also indicate that the potential impact of seal predation is greatest at the start of the year. This is particularly important as early running salmon sub-stocks are currently experiencing a decline in abundance (Youngson *et al.* 2002). For rivers like the River Conon, which do not support fisheries early in the year, this effect is of no consequence. However, for small rivers like the River Moriston, during January and February, seal predation may have a large impact since the river has only a small population of spring salmon. Larger rivers like the River Spey are also affected most during this period, but due to the size of their spring salmon stocks, the impact is likely to be less.

There are several potential sources of bias associated with the assumptions of the model, and it does not take account of the impacts that seals may have on stocks and fisheries other than as a result of direct mortality. The estimates given should therefore only be considered as indicative of the number of salmon consumed by seals rather than quantitative predictions of total impact. Nonetheless, our model is useful in demonstrating that the scale of salmon populations is important in determining a targeted approach to seal predation. This is particularly important when considering the conservation and management of protected and/or depleted salmon and seal populations.

Acknowledgements

We are grateful to the Conon and Spey District Salmon Fishery Boards, and Invermoriston Estate for allowing the use of their rod catches.

References

Butler, J.R.A. (2004). *Moray Firth Seal Management Plan; a Pilot Project for Managing Interactions Between Seals and Salmon in Scotland.* Spey Fishery Board, Aberlour, Morayshire, UK.

Butler, J.R.A. (2005). *Spey Fishery Board Annual Report & Accounts, 2004.* Spey Fishery Board, Aberlour, Morayshire, UK.

Friedland, K.D., Hansen, L.P., Dunkley, D.A. & Maclean, J.C. (2000). Linkage between ocean climate, post-smolt growth, and survival of Atlantic salmon (*Salmo salar* L.) in the North Sea area. *ICES Journal of Marine Science* **57**, 419-429.

Hilton, J., Welton, J.S., Clarke, R.T. and Ladle, M. (2001) An assessment of the potential for the application of two simple models to Atlantic salmon, *Salmo salar*, stock management in chalk rivers. *Fisheries Management and Ecology* **8**, 189-205.

Middlemas, S.J. (2003) *Interactions between harbour seals (Phoca vitulina) and salmonids (Salmo spp.) in estuarine environments.* PhD thesis, University of Aberdeen, Scotland

Olesiuk, P.F. (1993) Annual prey consumption by harbor seals (*Phoca vitulina*) in the Strait of Georgia, British-Columbia. *Fishery Bulletin* **91**, 491-515.

Tollit, D.J. (1996) *The diet and foraging ecology of harbour seals (Phoca vitulina) in the Moray Firth, Scotland.* PhD Thesis, Aberdeen University.

Williamson, G.R. (1988) Seals in Loch Ness. *The Scientific Reports of the Whales Research Institute* **39**, 151-157.

Youngson, A.F., MacLean, J. C., & Fryer, R. J. (2002) Rod catch trends for early-running MSW salmon in Scottish rivers (1952-1997): divergence among stock components. *ICES Journal of Marine Science* **59**, 836-849.

Reporting on grey and common seal interest features of Special Areas of Conservation in Scotland

Scottish Natural Heritage

NOTE: THIS PAPER AND ITS CONTENTS SHOULD NOT BE REFERENCED WITHOUT PRIOR PERMISSION OF THE AUTHORS

Background

The grey seal *Halichoerus grypus* is an interest feature of six Special Areas of Conservation in Scotland and the common (harbour) seal *Phoca vitulina* is an interest feature of eight. Figure 1 shows the locations of these sites. Under the Conservation (Natural Habitats &c) Regulations 1994 as amended. Scottish Natural Heritage has a responsibility to report on the condition of all SAC interest features once every six years. The first reporting cycle ran from 1999 to 2005. Reports on the condition of all seal interest features were completed in June 2005 and the results will be published by JNCC in 2006. This paper summarises the approach that has been used by SNH in this first reporting cycle to assess the condition of common and grey seal interest features of SAC in Scotland.

Setting attributes and targets

The *UK common standards monitoring guidance for marine mammals* (Anon. 2005) was developed by the Interagency Marine Mammal Working Group to ensure consistency in monitoring and assessing the condition of marine mammal features between the statutory nature conservation agencies. The guidance includes background information on common and grey seals, advice on the 'attributes' and associated 'targets' that should be used to assess these interest features, together with advice on appropriate survey techniques.

In the context of Common Standards Monitoring an attribute of a species interest feature is defined by JNCC as 'a characteristic of a population of a species which most economically provides an indication of the condition of the interest feature to which it applies'. The UK guidance identifies mandatory attributes that must be assessed for grey and common seal interest features. These are shown in Table 1. Additional attributes of 'population adjacent to SAC' for common seals and 'pup production in adjacent colonies' for grey seals have been included to take account of relatively small-scale (local) movements of animals that may occur over the six year reporting period. These attributes only contribute to the condition assessment if the attributes of 'population within SAC' and 'pup production within SAC' are not met.

The UK guidance suggests that distribution attributes should be assessed via the production of a map showing the distribution of either moulting common seals or grey seal pups within each SAC. The link between such a map and the assessment of the condition of the interest feature was unclear. Following discussion with SMRU, it was decided that a practicable alternative to the production of a map, would be to look at the presence or absence of seals within defined sections of each site that were known to be used regularly by moulting common seals or grey seal pups. For common seals within composite SAC (i.e. those made up of a number of different parts such as Yell Sound Coast), the site boundaries were used to define sections and, for others, the counting boxes used by SMRU during their moult season surveys were adopted, with some minor alterations (see Figure 2). For grey seals, specific areas were identified in discussion with SMRU (see Figure 3).

The target used for each attribute is also shown in Table 1. All targets for common and grey seal interest feature attributes consider trends rather than setting numerical thresholds. This approach has been taken because of the sometimes large interannual fluctuations in seal counts and our limited ability to interpret these with confidence. For some common seal sites, counts were made only once during the reporting cycle. In these cases, as well as for some sites where trends during the reporting cycle were not obvious, the data were compared against counts made before 1999 to provide context. Note that at the time the SAC were identified it was assumed that the interest features were in a favourable condition.

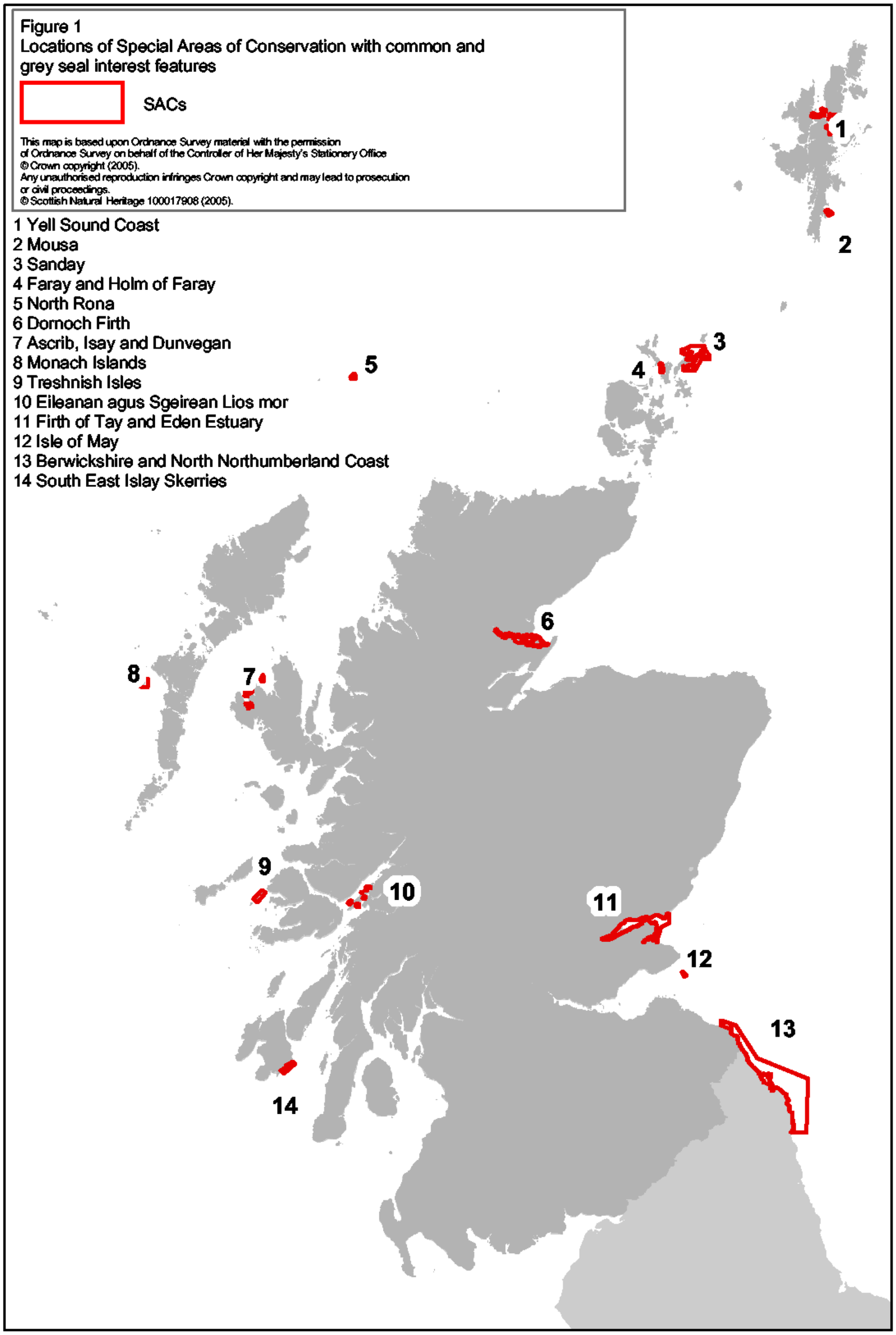


Figure 1
Locations of Special Areas of Conservation with common and grey seal interest features
SACs
This map is based upon Ordnance Survey material with the permission of Ordnance Survey on behalf of the Controller of Her Majesty's Stationery Office
© Crown copyright (2005).
Any unauthorised reproduction infringes Crown copyright and may lead to prosecution or civil proceedings.
© Scottish Natural Heritage 100017908 (2005).
1 Yell Sound Coast
2 Mousa
3 Sanday
4 Faray and Holm of Faray
5 North Rona
6 Dornoch Firth
7 Ascrib, Isay and Dunvegan
8 Monach Islands
9 Treshnish Isles
10 Eileanan agus Sgeirean Lios mor
11 Firth of Tay and Eden Estuary
12 Isle of May
13 Berwickshire and North Northumberland Coast
14 South East Islay Skerries
1
2
3
4
5
6
7
8
9
10
11
12
13
14

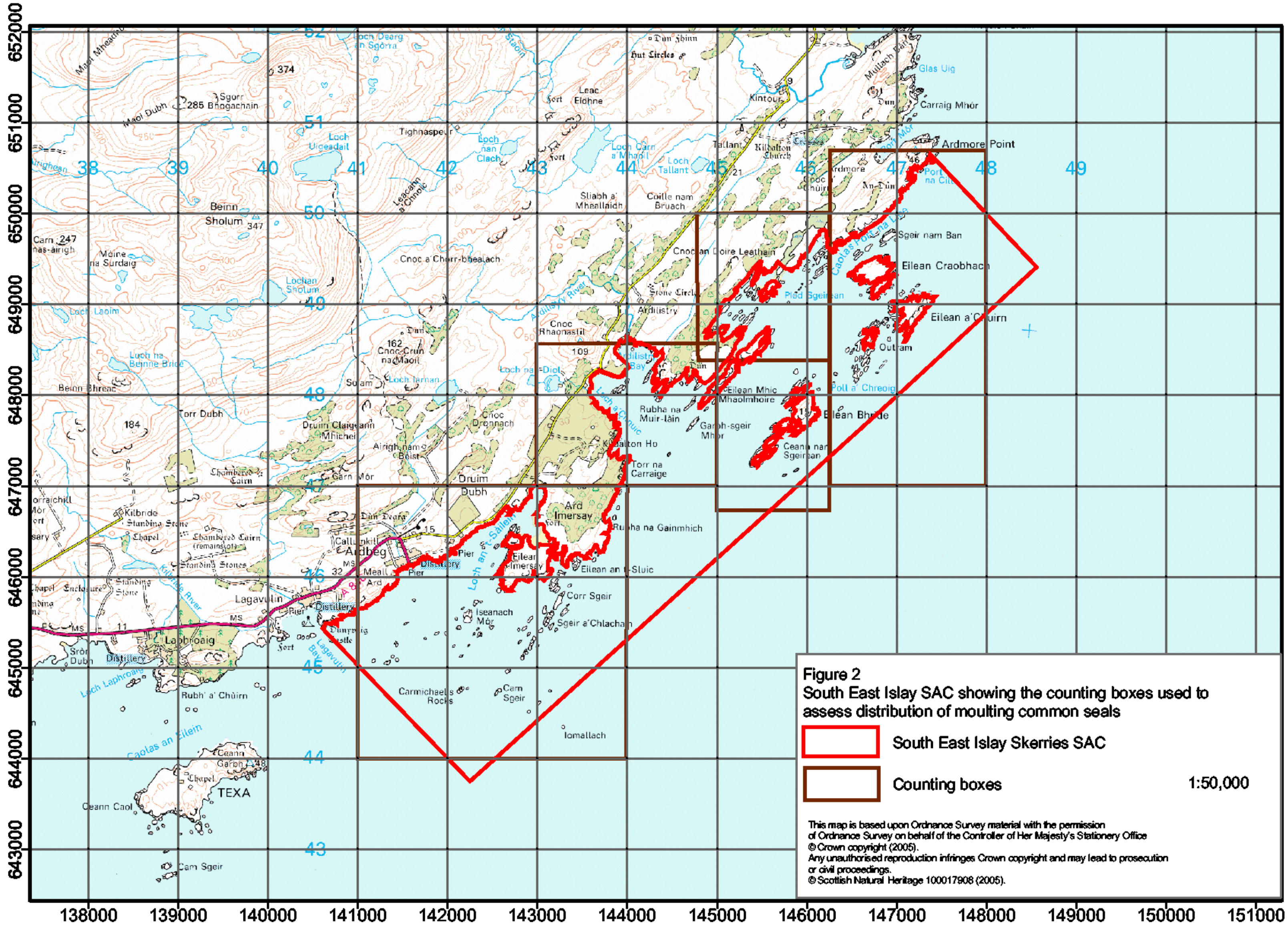


Figure 2
South East Islay SAC showing the counting boxes used to assess distribution of moulting common seals

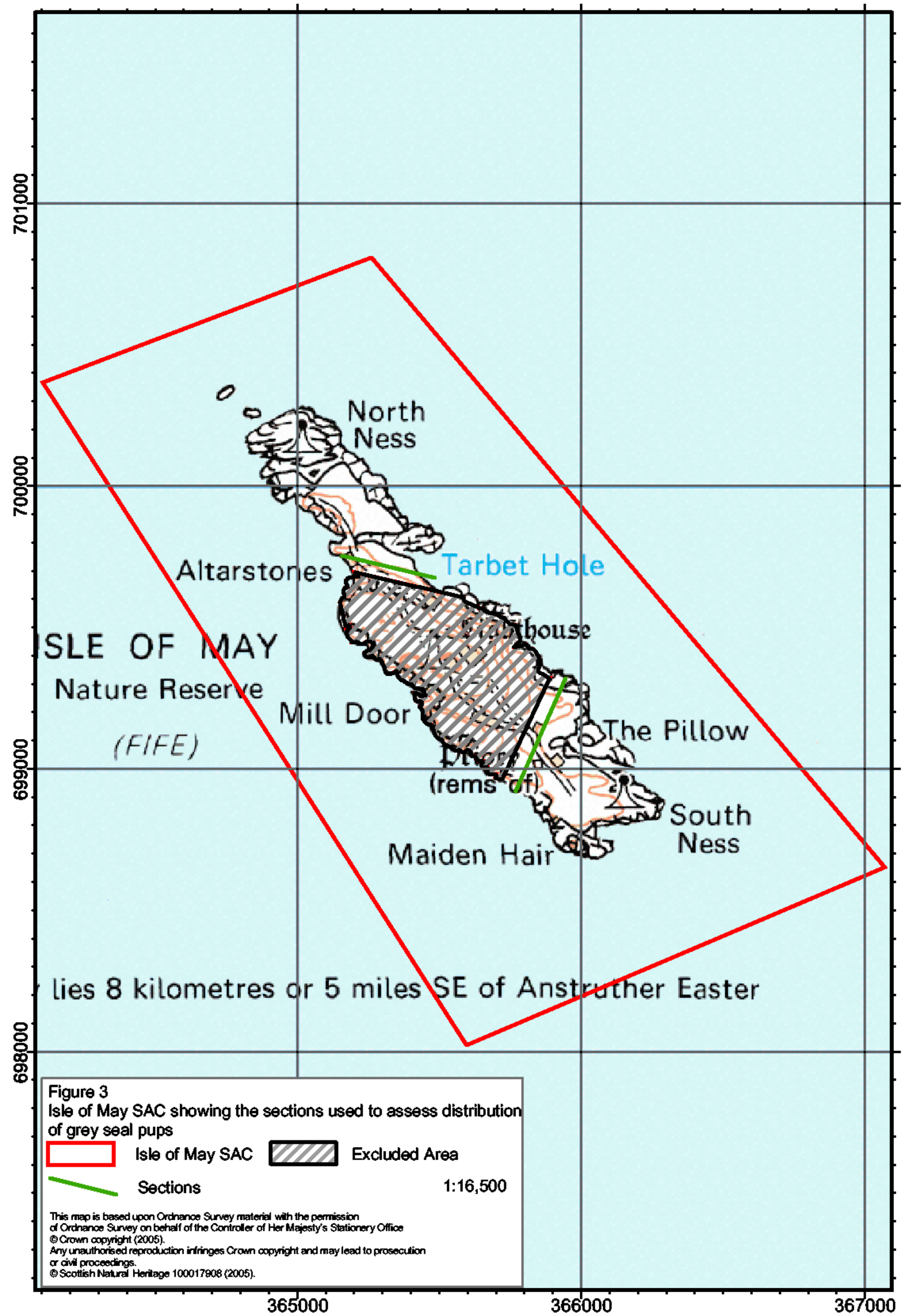


Figure 3
Isle of May SAC showing the sections used to assess distribution of grey seal pups

Table 1 Mandatory attributes for assessing grey and common seal interest features

Interest feature	Attribute	Target	Interest feature	Attribute	Target
Common seal	Population within SAC	A stable or increasing number of common seals within the SAC	Grey seal	Pup production within SAC	A stable or increasing number of breeding female grey seals within the SAC
Common seal	Distribution of common seals within SAC	A stable or increasing distribution of common seals within the SAC	Grey seal	Distribution of pups within SAC	A stable or increasing distribution of pups within the SAC
Common seal	Extent and distribution of suitable habitat	No loss in extent or distribution of suitable habitat within SAC	Grey seal	Extent and distribution of suitable habitat	No loss in extent or distribution of suitable habitat within SAC
Common seal			Grey seal	Accessibility of SAC to grey seals for pupping	Stable or increasing accessibility to pupping sites within the SAC.

Results

The data used to assess whether or not the targets had been met are described in Annex 1. Five of the six grey seal features were assessed as 'favourable (maintained)'[8] and one, North Rona, was assessed as 'unfavourable (declined)'. Pup production within this SAC has declined and the reasons for this are not clear.

Six common seal features were assessed as 'favourable (maintained)' and two, Mousa and the Dornoch Firth and Morrich More, as 'unfavourable (declined)'. Disturbance caused by visitors and by shooting respectively are believed to have led to the declining abundance of common seals within the SAC. Appropriate management measures are now in place at both sites. These two issues were also noted as potential problems at other sites and may require further consideration to determine whether any new site management measures are required to ensure their assessment as 'favourable (maintained)' in the future.

Other relevant work within SAC

The SNH/SMRU/SE PhD studentship on monitoring common seals within SAC has used a range of different techniques at different sites including tagging work, photo-identification and regular repeat counts during the breeding and moulting seasons. Other relevant work carried out by SMRU includes tagging in the Northern Isles as part of the Strategic Environmental Assessment work for the Department of Trade and Industry (Hammond *et al.* 2003, Hammond *et al.* 2004 and Sharples *et al.* 2004) and boat counts in south-east Scotland (Sharples 2005). More detailed work on population structure and movement of common seals in the inner Moray Firth has been carried out by Aberdeen University's Lighthouse Fieldstation since the late 1980s. The latter is now supported by SMRU as part of a broader research programme that was developed to support the Moray Firth Seal Management Plan and improve understanding of seal-salmonid interactions.

SNH Area Offices have also either commissioned work or carried out studies themselves. This includes boat counts at Eileanan agus Sgeirean Lios Mor which were re-started in the summer of 2005, studies of visitor disturbance on Mousa (Brown & Prior 1998) and within Tentsmuir NNR, part of the Firth of Tay and Eden Estuary SAC. The work on visitor disturbance on Mousa has been continued more recently by the RSPB (Smale 2004).

SMRU have carried out more detailed long-term studies, including tagging, on the grey seal colonies on North Rona and the Isle of May. SMRU's studies on grey seal populations in the UK includes work on the populations within the SAC in Scotland. This work has involved looking at population size and status, offshore foraging, diet, colony development and movement and dispersal from and between colonies (see, for example, Twiss 2001, Twiss *et al.* 2003 and Pomeroy *et al.* 2005). On the Farne Islands the National Trust monitor grey seals every four days during the pupping season (e.g. Walton 2005).

[8] The seven categories used in the UK are favourable (maintained), favourable (recovered), unfavourable (recovering), unfavourable (no change), unfavourable (declining), destroyed (partially destroyed) and destroyed (totally destroyed).

SAC in the rest of the UK

There are two other SAC that were identified because of the presence of seals. Pembrokeshire Marine SAC in Wales was identified for grey seals and The Wash and North Norfolk Coast SAC in England was identified for common seals. Monitoring work has been carried out by the Countryside Council for Wales and English Nature respectively, but work on reporting is not yet complete.

Conclusions

The approach that SNH has used to assess the condition of common and grey seal interest features was largely based on the *UK common standards monitoring guidance for marine mammals*. Two changes were made. The main change involved defining an adjacent area (for common seals) or identifying adjacent colonies (for grey seals) and this allowed the assessment to take account of relatively small-scale (local) movements of individuals that may occur during the six year reporting period. The other, smaller, change was to the way in which distribution has been assessed by looking at presence or absence of seals within defined sections of each SAC. SNH considers that these changes improved the final condition assessments, the former allowing the ecology/behaviour of the animals to be better reflected and, the latter being a more practical option in that the data used were already recorded in this way by SMRU and therefore did not require additional processing. The results of this and other work, in particular the SNH/SMRU/SE PhD looking at monitoring common seals within SAC, will be used to review the methods and refine the approach to be used for assessing the condition of grey and common seal interest features in future reporting cycles.

Preparation of paper

This paper has been prepared by Katie Gillham, Maritime Advisory Officer for SNH. It is based on discussions with John Baxter, Head of Habitats and Species Unit, SNH.

Acknowledgements

Staff at SMRU for discussion and, in particular, Callan Duck and Beth Mackay for providing the data from the long-term monitoring studies carried out by SMRU and comments on interpretation.

References

Anon (2005) UK common standards monitoring guidance for marine mammals JNCC ISSN 1743-8160 (online) http://www.jncc.gov.uk/pdf/csm_marine_mammals.pdf

Brown, E & Prior, A (1998) Recreational disturbance to breeding seabirds and seals on Mousa SSSI. Unpublished report to SNH.

Hammond, P.S., MacLeod, K., Northridge, S.P., Thompson, D. & Matthiopoulos, J. (2003). Background information to marine mammals. Strategic Environmental Assessment 4. Consultation document for the Department of Trade and Industry.

Hammond, P.S., Northridge, S.P., Thompson, D., Gordon, J.C.D., Hall, A.J., Sharples, R.J., Grellier, K. and Matthiopoulos, J. (2004). Background information on marine mammals relevant to Strategic Environmental Assessment 5. Consultation document for the Department of Trade and Industry.

Pomeroy, P.P., Redman, P.R., Ruddell, S.J.S., Duck, C.D. & Twiss, S.D. (2005) Breeding site choice fails to explain interannual associations of female grey seals. Behav Ecol Sociobiol 57: 546-556.

Sharples R 2005 *Ecology of harbour seals in southeastern Scotland* Unpublished PhD Thesis, University of St Andrews.

Sharples, R.J., Matthiopolous, J. and Hammond, P.S. (2004). Distribution and movements of harbour seals around Orkney, Shetland and the Wash. Consultation document for the Department of Trade and Industry. Crown.

Smale, JR (2004) Observations of the effects of management measures on Mousa. Unpublished report to the Royal Society for the Protection of Birds.

Twiss S.D. (2001). Reproductive performance links to fine scale spatial patterns of female grey seal relatedness. Proc. R. Soc. Lond. B. 268: 711-717.

Twiss, S.D., Pomeroy, P.P. & Duck, C.D. (2003) Grey seal pup mortality is not explained by local breeding density on the island of North Rona, Scotland. J. Zool. Lond. 259, 83-91.

Walton (2005) The Farne Islands: the grey seal (Halichoerus grypus) breeding season – 2004. Unpublished report to the National Trust.

Annex 1 Sources of data used to assess condition of common and grey seal interest features

The data used to report on the condition of common and grey seal features have mainly come from work carried out by SMRU. For the assessment of the common seal attributes 'population within the SAC', 'population adjacent to the SAC' and 'distribution of population within SAC', data from SMRU's approximately five-year monitoring programme of common seals during the annual moult in August were used. Some information from the SNH/SMRU PhD looking at techniques for monitoring common seals within SAC was also used.

For the assessment of grey seal attributes 'pup production within SAC', 'pup production in adjacent colonies' and 'distribution of pups within SAC', data from SMRU's monitoring programme in which each discrete breeding colony is photographed between three and seven times every year during the breeding season were used.

There have been no previous assessments of the attribute 'extent and distribution of suitable habitat within SAC' for either grey or common seals. Aerial photographs are being used to assess this attribute. SNH already holds these for most SAC with grey and common seal interest features. Sites not currently covered will be photographed in the next reporting cycle.

Information on activities within and adjacent to each SAC was provided by SNH Area Officers and SMRU. The Royal Society for the Protection of Birds (RSPB) provided additional information on visitor management within Mousa SAC and the National Trust provided information on the Farne Islands within the Berwickshire and North Northumberland Coast SAC. This contributed to the assessment of 'distribution and extent of suitable habitat' for both species and for 'accessibility of SAC to grey seals for pupping'.