Scientific Advice on Matters Related to the Management of Seal Populations: 2002

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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 at the end of this document.

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 to government scientific review 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 2002. 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). Appended to the main report are two annexes giving more detail about the status of the two species of seal around Britain: grey and common (harbour) seals.

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 (Annex I, Table 1). There are two centres of population in the North Atlantic; one in the region of Nova Scotia and the Gulf of St Lawrence and the other around the coast of the UK and especially in Scottish coastal waters. The largest population is in Canada. Populations in all three centres are increasing, although numbers are still relatively low in the Baltic where the population went through a long-term decline possibly caused by reproductive failure due to pollution.

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 between trips to forage for food at sea. Female grey seals give birth to a single white-coated pup, which moults and is abandoned by its mother about 3 weeks later.

About 38% of the world population of grey seals is found in Britain and over 90% of British grey seals breed in Scotland, the majority in the Hebrides and in Orkney (Annex I, Table 1). There are also breeding colonies in Shetland, on the north and east coasts of mainland Britain and in southwest Britain. 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 2001, there were an estimated 42,000 grey seal pups born in Britain. This equates to a total population of about 130,000 grey seals.

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

Grey seals feed mostly on fish that live on or close to the seabed. The diet is composed particularly 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 oiliness of the prey but an average figure is 7 kg of cod or 4 kg of sandeels per day.

Common 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 (Annex I, Table 2). 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 particular concentrations in the Wash, Firth of Tay and the Moray Firth

Between 1996 and 2001, 34,625 common seals were counted in the whole of Britain, of which 30,196 (87%) were in Scotland and 4,245 (13%) were in England. The total British population cannot be estimated accurately because it is not possible to count all individuals in the population. Accounting for those animals that are not seen during surveys 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 severely affected by the phocine distemper virus (PDV) epidemic in 1988. Numbers in England have increased since then, but have only recently recovered to the pre-epidemic level. The new epidemic in 2002 is likely to have a similar impact to the one in 1988.

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 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 without a white coat and can swim almost immediately.

Adult common seals typically weigh about 80-100 kg. Males are slightly bigger 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 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, perhaps 3-5 kg per day depending on the prey species.

Current status of British grey seal populations

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 include 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 Annex II and Annex IV.

Pup production

The total number of pups born in 2001 at all annually surveyed colonies was estimated to be 36,920. A further 5,000 pups were likely to have been born at other scattered sites. Regional estimates were 2,938 in the Inner Hebrides, 12,325 in the Outer Hebrides, 17,523 in Orkney, and 4,134 at North Sea sites.

Pup production and total population size estimates for the main colonies surveyed in 2001

Location	2001 pup production	Change in pup production from 2000-2001	Change in pup production from 1997-2001	Total 2001 population (to nearest 1000)
Inner Hebrides	2,938	-8.8%	-0.5%	9,000
Outer Hebrides	12,325	-8.0%	+1.4%	38,000
Orkney	17,523	+9.6%	+4.4%	54,000
Isle of May + Fast Castle	2,253	-10.4%	+3.3%	7,000
All other colonies	3,500			11,000
Total (Scotland)	38,539			119,000
Donna Nook	634	+2.6%	+14.5%	2,000
Farne Islands	1,247	+6.5%	-1.7%	4,000
SW England & Wales (last surveyed 1994)	1,500			5,000
Total (England)	3,381			11,000
Total (UK)	41,920	0.0%*	+2.8%	130,000

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

Trends in pup production

Between 1984 and 1996, estimates of the total number of pups born at regularly surveyed colonies increased year on year (Annex II, Figures 2 & 3). A small decline was observed in 1988 that was probably related to the effect of a phocine distemper epidemic that mainly affected common seals at that time. Following this event, estimated total pup production did not show any decline until 1997. It recovered again in 1998 then declined at all major breeding colonies in 1999. The greatest decline was at the Farne Islands, where pup counts are made by National Trust staff on the ground. That declines occurred at the Farne Islands and at other sites where pup production is monitored by aerial survey suggested that this was a general phenomenon and not related to differences in methods or survey conditions from previous years. Estimated pup production then increased in 2000 at all regularly surveyed breeding sites.

In 2001 the pup production at regularly surveyed sites was similar to that observed in 2000. This reflects a situation in which increases in some regions, such as Orkney were balanced by declines in others, such as the Hebrides. Calculating rates of change over longer periods is more indicative of recent trends at major breeding sites. It shows, for example, that pup production in the Hebrides has not changed significantly over the past 5 years and that the average annual increase in pup production at the main breeding sites between 1997 and 2001 was 2.8%. This compares with 5.2% between 1992 and 1996 and 6.2% between 1987 and 1991(see Annex II). There is, therefore, some evidence for a slowing in pup production in recent years.

The total number of pups born is the sum of pup production at many individual colonies, and because this varies from year to year, fluctuations in total pup production should also be expected. However, declines in pup production in 1999 appeared to be too great and too widespread to be explained solely by changes in survival and pregnancy rates related to shortage of space at breeding colonies.

Population size

The estimated size of the UK grey seal population at the start of the 2001 pupping season was about 130,000 individuals. Taking account of uncertainty, this could range from less than 112,000 to as many 147,000 seals. The majority of these, approximately 91.5% (119,000), are associated with breeding colonies in Scotland and the remainder, 8.5% (11,000), with colonies in England and Wales.

Uncertainty in estimates

There is considerable uncertainty associated with the total population estimates provided in the table above. Each estimate of pup production could lie within a range of –14% to +13% of the values provided and there are similar levels of uncertainty associated with other factors used to calculate total population size. In addition to this, the estimates of total population size assume that males have similar demography to females. Male mammals normally die younger than females. Therefore, depending upon the degree to which this is true in grey seals, the estimates of total population size in the table may be greater than the actual population size.

Trends in population size

The average rate of increase in the grey seal population associated with annually monitored sites over the past 5 years (1997-2001), is +5.6%. Overall, this does not represent a significant change in the rate of increase compared to the previous 5 years (1991-1996).

Even if pup production is stabilising in some regions and if these recent changes in pup production continue, the grey seal population as a whole is likely to continue increasing. This is especially the case if the observed changes in pup production are caused by reduced pregnancy rate in the seals rather than by an increase in the death rate of adults.

Current status of British common seal populations

Each year SMRU carries out surveys of common seals during the moult in August. It is impractical to survey the whole of the coastline every year but current plans by the 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 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 uncertainties. The largest contribution to uncertainty is the proportion of the seals not counted during the survey because they are in the water. We cannot be certain what this proportion is and it is likely to vary from region to region and in relation to factors such as state of the tide and weather. Efforts are made to reduce the effect of these factors by standardising the 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 numbers are normally presented as minimum estimates of population size. It is on this basis that the most recent count totalling about 34,600 common seals is likely to indicate a total population of 50,000-60,000 seals.

Scotland

During 2001, common seal distribution and abundance was estimated for Orkney and Shetland. This followed surveys in 2000 of the Inner and Outer Hebrides, Firth of Tay and the Inner Moray Firth. These surveys were mainly targeted at sites proposed as Special Areas for Conservation under the European Habitats Directive and were part-funded by Scottish Natural Heritage. A previous analysis of data from surveys of common seals along the north and west coasts of Scotland as far south as the southern tip of the Mull of Kintyre, and in Orkney, Shetland and the Hebrides indicated that there was an overall increase of about 3% per year in the number of animals counted at haul-out sites between 1988 and 1997. However, because of a high level of uncertainty, these changes could be caused by differences in the behaviour or distribution of seals between surveys, or in the environmental conditions when surveys were carried out. Comparing the surveys carried out in 2000 with those in 1996/97 suggested that there were more common seals in the west Highland and Strathclyde regions and a small decline in numbers in the Outer Hebrides and the Inner Moray Firth. Data from the surveys carried out by the University of Aberdeen suggest a continued decline in numbers in the Inner Moray Firth.

The surveys conducted in 2001 indicated that common seal numbers had declined by 9% and 18.5% in Orkney and Shetland respectively since the previous survey in 1997. However, the counts in 2001 were within the range of the counts obtained from the previous three surveys carried out in these regions since 1989. Considering the uncertainties surrounding the counting methods, it is not possible to conclude from the data currently available that there has been a change in the size of the common seal population in Orkney and Shetland during the past 10 years.

The Wash and eastern England

One complete aerial survey of common seals was carried out in Lincolnshire and Norfolk during August 2001. The count for The Wash (3194) was the highest ever recorded. It was 15% greater than the mean of the 2000 counts (2,778) and 5% greater than the higher of the 2000 counts (3,029). The average annual rate of increase in the number of seals counted in The Wash since 1989 is 6.3% (SE = 0.60%). This is significantly greater than the 3.5% (SE = 0.29%) average annual rate of increase between 1968 and 1988.

Minimum estimate of the British common seal population

Surveys of Orkney and Shetland were carried out in 2001. The most recent minimum estimate of the number of common seals in Scotland is 30,196 from surveys carried out in 1996, 1997, 2000 and 2001. The most recent minimum estimate of common seal numbers for the east coast of England is

4,409. This comprises 4,274 seals in Lincolnshire and Norfolk in 2001 plus 135 seals in Northumberland, Cleveland, Essex and Kent between 1994 and 1997.

Possible effects of phocine distemper virus (PDV)

The 2001 count of common seals in The Wash exceeded the 1988 pre-epidemic count by 5%. It has taken 13 years for the population to recover from the effects of the PDV epidemic. This is in contrast to populations on the east and south sides of the North Sea, which recovered more rapidly and were similar to or exceeded their pre-epidemic levels by 1996.

During the previous outbreak of phocine distemper virus it is thought that about 10% of the common seal population in Scotland and up to 50% of common seals in England may have died. The current PDV outbreak has strong similarities in terms of its geographical origins and the chronology of infection to the outbreak in 1988 but there are detailed differences that could be important.

Counts by region are given in the Table below. These are minimum estimates of the British common seal population which is thought to be approximately 50,000-60,000 animals.

Region	**1996-2001**
Shetland	4,883
Orkney	7,752
Outer Hebrides	2,413
Highland (Nairn to Appin)	6,291
Strathclyde (Appin, Loch Linnhe to Loch Ryan)	7,909
Dumfries & Galloway (Loch Ryan to English Border at Carlisle)	6
Grampian (Montrose to Nairn)	126
Tayside (Newburgh to Montrose)	165
Fife (Kincardine Bridge to Newburgh)	611
Lothian (Torness Power Station to Kincardine Bridge)	40
Borders (Berwick upon Tweed to Torness Power Station)	0
TOTAL SCOTLAND	**30,196**
Blakney Point	772
The Wash	3,194
Donna Nook	233
Scroby Sands	75
Other east coast sites	135
South and west England (estimated)	20
TOTAL ENGLAND	**4,429**
TOTAL BRITAIN	**34,625**

Questions from the Scottish Executive Environment and Rural Affairs Department

General

How can population dynamics analysis models assist in estimating the potential impact of disease or population management measures on seal populations?

The response to the question is in three parts: an introduction of the modelling used to understand seal population dynamics and then separate responses to the two parts of this question.

Population modelling

Population models use the underlying process of birth, death, immigration and emigration to generate the likely trajectory of seal populations. By fitting these models to data from population counts it is possible to gain an understanding of the processes driving change within a population. However, there can be considerable uncertainty surrounding the processes that affect birth and death rates, as well as those that affect immigration and emigration. This can lead to several plausible models, all of which are consistent with the available data. This suite of plausible models can then be used to forecast the possible range of future trends in the population.

Where British grey seals are concerned, uncertainty around these predictions arises from several sources:

(1) Estimates of birth rates for the population as a whole are based entirely on data collected in the 1970's and early 1980's. SMRU has no plans to use culling to obtain new data and there is no guarantee that the data from the 1980s apply to the current population. New methods involving the long-term observation of individuals at breeding colonies are being used to augment these older data.

(2) Death rates have been estimated from the age structure of seals shot in the 1970's and these also may not be accurate in the present day. Again, new methods of mark-recapture are being developed and these could provide some information about death rates.

(3) There is very little information about rates of migration between individual seal colonies. However, new techniques to estimate these rates from genetic and mark-recapture experiments are being developed.

(4) We have relatively little information about how birth, death, immigration and emigration rates are likely to vary with the density of animals in the population.

On the positive side, there is greater certainty in the estimated number of pups born each year. The value of these estimates is enhanced by the long time-series (stretching back to the late 1960's in many areas) and the fine spatial resolution of these estimates because they are specific to each breeding colony.

The approach being adopted to the modelling of the grey seal population by the Sea Mammal Research Unit (SMRU) is, therefore, to develop models that use birth/death and immigration/emigration rates that explain the greatest level of variation in the spatial and temporal distribution of the number of pups being born.

In collaboration with the Centre for Research into Ecological and Environmental Modelling at the University of St Andrews, SMRU is developing a fully spatially explicit model of British grey seal population dynamics that will be used to forecast trends in abundance.

The situation for modelling the changes in common seal populations and the effects of management is considerably less developed than for grey seals. There is no equivalent base line of data about number of births each year. We currently have to use data for populations from outside the UK, although recent mark-recapture studies in the Moray Firth will provide information about birth and death rates. Therefore models for common seals with equivalent capabilities to those for grey seals are not feasible at present. More generalised models of seal population dynamics can provide very broad predictions of the effects of different management regimes.

<u>Assessment of the impact of disease</u>
The situation is different in the case of disease epidemics, to which common seals appear to be more vulnerable than most other seal species. Predictive models of the way in which phocine distemper virus (PDV) spreads through a common seal population have been developed by the University of Cambridge in collaboration with SMRU. However, these models are sensitive to the characteristics of the disease. New strains of a disease like PDV could result in degradation of the predictive power of these types of models.

Nevertheless, the current models of PDV predict that the disease is unlikely to recur less than 10 year after a previous outbreak. The current outbreak has recurred 14 years after the previous outbreak. In future, it will be possible to build this type of disease process into management models for common seal populations.

<u>Assessment of population management measures</u>
A good population model is an essential tool for assessing the effectiveness of management measures. A model that has been demonstrated to be realistic can be used to experimentally manipulate the population in advance of any management decisions being made. This will allow examination of the outcome of different management scenarios. Much of the uncertainty about possible outcomes of different management measures arises because of the uncertainties surrounding the data used to model seal populations. Nevertheless, it is still possible to examine management options using a precautionary approach. If the objective was to be precautionary about seal populations, this would entail running models for the worst case rather than the most likely case.

SMRU is developing a model that will allow this approach. This will permit SMRU to investigate the potential outcomes of different management approaches if or when they are proposed.

Grey Seals

Is there any evidence to suggest that the Scottish grey seal population is stabilising?

In the recent past, the UK Special Committee on Seals has noted that the rate of increase in pup production amongst grey seals has slowed in some regions. For example, in the Hebrides, pup production has not increased significantly since 1992. The pattern observed in the Hebrides could be being repeated in the Orkneys where pup production increased at 9.6% in the five years to 1996 and was 4.4% in the past 5 years. (Since number of births varies between years, it is advisable to consider percentage changes in pup production averaged over about 5 years). However, it should be noted that the overall trend in pup production for the total population is still upwards and it is still too early to say if the rate of increase in pup production in Orkney has changed significantly.

Pup production is used as an indicator of population size in grey seals. This assumes that changes in pup production are not compensated by changes in other factors like the juvenile survival rate. Changes in pup production can also take many years to filter through to equivalent changes in the population as a whole. If the increase in pup production has declined because of reduced birth rates then it could take more than 10 years before there is an equivalent change in the size of the entire population. This is because grey seals are very long-lived. However, if the rate of increase in pup production has declined because of reduced survival of adults then the change in pup production reflects a change in the rate of increase in the population as a whole. At present, there is no way of distinguishing between these possibilities but the former scenario, in which it may take 10 or more years for the population as a whole to follow the trend in the pup production, is believed to be the more likely.

Overall, the balance of evidence indicates that the grey seal population in Scotland will eventually stabilize, but it is not possible to say precisely when this will occur. It is likely that this will happen first in the Hebrides. The North Sea colonies as a whole are showing a gradual overall decline in the rate of increase in pup production and the fluctuations in pup production in Orkney in recent years could indicate that the population is approaching its limits

Is there any evidence that new seal breeding sites are developing and is such growth monitored?

There is some evidence of the development of new breeding sites for grey seals. For example, at Fast Castle (Berwickshire) a colony developed about 7 years ago and initially increased quickly (Appendix to Annex II, Table 4). Two additional colonies have formed in Orkney in recent years and the colony at Helmsdale, Sutherland, has increased through colonisation of previously unused beaches between Berriedale and Duncansby Head. All new colonies are included in the Sea Mammal Research Unit's (SMRU) annual surveys of grey seal colonies. This is SMRU's standard procedure when monitoring small breeding colonies.

Although SMRU does not have the capability to search all potential breeding colonies annually, SMRU monitors over forty existing small colonies within a three to five year cycle. Many of these colonies are surveyed in alternate years. In addition, islands and coasts that appear to provide suitable breeding habitat are also surveyed and the annual grey seal surveys allow inspection of large areas of coastline where new colonies could have formed. SMRU also incorporate information passed on by other observers, particularly regional staff of Scottish Natural Heritage. Grey seals can also give birth at unusual sites from time-to-time. Nevertheless, the total number involved forms a very small proportion (likely to be <1%) of the total pups born at other sites and, as such, does not presently constitute a significant proportion of the UK population.

If so, how is this reflected or how can this be reflected in population estimates?

The total population is estimated from the pup production. The proportion of pup production not accounted for at the annually monitored sites is estimated to be less than 15% of the total. The information from these sites is obtained on a less formal basis but is, nevertheless, included in the overall population estimates. The information from these other sites is tabulated annually in the Advice (Annex II, Table 2). The region requiring the most urgent attention is Shetland, which was previously surveyed in its entirety in 1977, with a partial survey in 1994 by E. Brown, under contract to Scottish Natural Heritage.

How can the latest information on habitat use by grey seals outwith the breeding season be used to further our understanding of their interactions with fisheries?

Over the past 10 years, SMRU has undertaken studies to examine the distribution of grey seals outside the breeding season. This has involved tracking individuals at sea and developing statistical methods to extrapolate from this sample to the whole population. The latest summary information is provided in Figure 1. Further details are provided in Annex V, Information Paper 3. This shows clear concentrations of foraging effort in grey seals. It is not possible to say what impact this distribution might have on marine fish stocks, but two important features are worth noting: (1) most of the foraging by grey seals occurs offshore (>10 miles from land) and is not associated with regions immediately surrounding the locations where they are observed ashore and (2) these areas are not necessarily those used most intensively by fisheries.

SMRU will continue to improve this estimated distribution by accounting for the different behaviour of males and females, and juvenile adult seals, and by considering changes depending upon time of year.

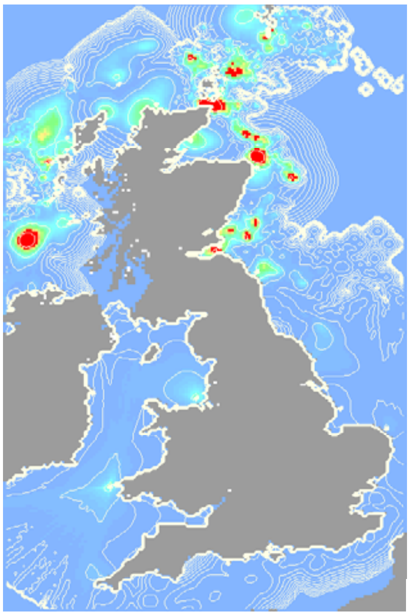

Figure 1. The estimated distribution of grey seals around the UK coast at times of year other than the breeding season and when not hauled out on land. The estimate is based upon the distribution of 108 grey seals tracked using satellite tags.

Common Seals

How could current estimates of common seal numbers and in particular the identification of population trends be improved?

Recent estimates of common seal populations have been made using aerial surveys which provide a synopsis of common seal abundance in large regions of coastline (each region is about one-fifth of the coastline of Scotland). In the past, SMRU has tried to survey at least one of these regions each year. Only in The Wash, the Moray Firth and the Firth of Tay is there an annual count of common seals. It has not been possible for SMRU to maintain its schedule of surveys in recent years, although specific regions have been surveyed more regularly under contract to Scottish Natural Heritage

These surveys provide information about the minimum number of seals within a region at the height of the moult (August). The moulting period is chosen because this is the time of year when the number of seals on land is greatest and most consistent. The method can only count seals while they are on land and, in order to translate this into a total population size, it is then necessary to adjust the estimate to account for those seals that were in the water at the time of the survey. This requires a detailed knowledge of the movements of a sample of individual common seals and this information is only available for a few of the regions surveyed and these mainly include sites where seals haul out on sand banks. This type of information is expensive to obtain, although new technology is helping to increase the practicality of the approach. SMRU has plans to undertake tracking of common seals in the Hebrides and is currently carrying out tracking studies on the east coast of Scotland.

To maximise the effectiveness of surveying, it will probably be necessary also to examine common seal numbers at specific sites more frequently and over longer time periods within a year than is possible using current methods. These could be described as trend sites. The degree to which these trend sites are representative of the whole population could be assessed from the synoptic aerial surveys. However, more research is required to assess the number of trend sites that will be required to provide reliable information.

Is it possible to estimate the potential impact of the latest Phocine Distemper Virus outbreak on Scottish Common seal populations?

The best indicator of the potential impact of Phocine Distemper Virus (PDV) on common seals in Scotland is the pattern of infection and death that were observed during the previous outbreak in 1988. The source and subsequent radiation of the current outbreak is following a similar pattern to that of 1988, although the disease appears to be taking longer to spread between local populations. During the 1988 outbreak common seals in Scotland were affected much less than anywhere else in Europe. Large numbers of dead seals were reported from the Moray Firth , Orkney, the west coast and the Clyde. However, when these populations were resurveyed in 1989, the only detectable decline in numbers (of around 10%) was on the east coast.

We do not know why common seals in Scotland were affected to a lesser extent than those in the southern North Sea. However, serological testing suggested that over 80% of Scottish seals were exposed to the virus suggesting that they were more resistant to the disease than seals in the southern North Sea and Baltic. Recent serology studies indicate that most common seals in the Scottish population are once again susceptible to the PDV virus.

Seal Diet

What progress is being made in the latest study of grey seal diet?

The Sea Mammal Research Unit is currently carrying out a study of grey seal diet in the North Sea, Orkney, Shetland and the Hebrides. This is funded by DEFRA, SEERAD and SNH and its objectives are to repeat a study of diet carried out by SMRU in 1985. A wider area will be covered in 2002 than in 1985. This is a 3-year project which is still in its first year. Scats have been collected in the Hebrides, Orkney, Shetland and along the North Sea coast beginning in January 2002. These samples are currently being analysed and further collections will take place across all these regions to ensure a representative set of samples is obtained throughout the year.

The Impact of Seals on Salmonids

Is it possible to establish whether individual seals specialise in salmonids?
If so, is it possible to estimate their impact on overall salmonid mortality?

It may be possible to establish if individual seals specialise in salmonids using methods that determine the relative abundance of fatty acids (i.e. building blocks of fat) in different fish species or species groups in the diet. This method requires knowledge of the fatty acids incorporated into the tissues of seals not only from salmon but also from all other potential prey species, including sea trout which may be particularly difficult to distinguish from salmon prey. In collaboration with the Scottish Fisherman’s Federation, SMRU is planning a project that, if funded, will provide a library of chemical profiles for each prey species that takes account of variations among regions and at different times of year. It will then be possible to compare profiles from individual seals with this library.

Estimating the contribution of seal predation to overall salmon mortality requires knowledge of all the other forms of mortality experienced by salmon. At present in Scotland there is a relatively large population of seals and small populations of salmon. Therefore, even if only a small proportion of the seal population eat adult salmon occasionally, they could have a substantial effect upon salmon populations. This has two consequences: salmon predation is likely to be a rare event when viewed in terms of the average seal, and it is difficult to obtain reliable estimates of seal predation on salmon.

It is likely that the greatest effects of seals on salmon occur in the entrances to the main rivers and this is the region in which we suggest that future research should be concentrated. There may be a case for carrying out experimental studies of seals that specifically occupy river systems to establish the extent to which they predate salmon, whether there are methods that could be used to create seal exclusion zones at some sites and whether the removal of "rogue" seals would be an effective strategy to reduce predation of salmon. However, studies of grey seals in the Baltic showed that removal of "rogue" seals had no effect on the apparent damage caused by seals to a coastal salmon fishery

What are the principle areas of uncertainty concerning seal/salmonid interactions and which of these areas might be tackled by focussed research?

This question can be answered on two levels because seal/salmonid interactions can be viewed as (1) an effect of seals on the population of salmon as a whole and (2) the effect of seals on salmon fisheries.

Considering the effect upon salmon populations as a whole, seals are only one of several different sources of mortality for salmon that could influence the size of a population and, therefore, the level of a fishery. There are large parts of the salmon life-history, from the production of smolts to the return of adults to rivers, that could be influenced by both environmental change/variability and by predation from species other than seals. At this stage, it is impossible to determine the principal uncertainties, although this question could merit specific theoretical studies to examine the sensitivity of salmon life-histories to predation at different stages. Seals are known to contribute to the mortality of salmon at various stages in their life cycle but the importance of seal predation for salmon populations as a whole is unknown.

A principal uncertainty involved in this assessment is whether seals are involved in predation of salmon in the open sea. Since salmon are large highly mobile fish, it is considered unlikely that seals will have the capability regularly to capture salmon in open water. Resolution of this question could come from focussed research on the diet of individual seals using fatty acids (as described above) and using state-of-the-art technology to study seal foraging behaviour
Considering the direct effects upon salmon fisheries, recent analyses of seal interactions with fisheries in the northeast Atlantic region suggest that seals are opportunists and will learn to use fishing gear to help capture highly mobile prey like salmon if the design of the fishing gear has not taken deterrence of seal predation into account. Therefore, focussed research on the design of fishing gear to reduce the capacity of seals to capture or damage salmon could be fruitful. Some new forms of net design used in Sweden are proving to be successful in this regard.

Non-lethal Methods of Population Control

Have there been any recent developments in relation to non-lethal methods of population control which could be effectively applied to Scottish seal populations?

SMRU is continuing to monitor developments in this field. The method of non-lethal population control that is most often proposed for Scottish seal populations is the application of immuno-contraception that renders females sterile for a number of years.

Recent applications of the method to the control of white-tailed deer and horse populations in the United States have apparently proved to be successful, at least in terms of the efficacy of the treatment to induce a degree of sterility. The long-term success as a measure of controlling larger populations remains to be tested.

There are a number of problems with applying this method to the control of grey seal populations. These include the degree to which it is possible to implement such a system of control across a sufficiently large section of the population, the costs involved and the extent to which the objective of reducing the impact of seals on fisheries might be achieved. Nevertheless, a small-scale trial to assess the biological side-effects, efficacy and the economics of such a system of population management in grey seals might be useful.

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.

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The Status of Grey and Common Seals in the North Atlantic Region

Table 1 Sizes of grey seal populations

Region	Population size	Year when latest information was obtained	Type of data (see key[1])	Population status
Mainland Scotland & Shetland	10,800	1998-2001	1	
Outer Hebrides	38,100	2001	2	Pup production stable, total population probably still increasing
Inner Hebrides	9,100	2001	2	Pup production stable, total population probably still increasing
Orkney	54,200	2001	2	Increasing
Scottish North Sea coast	7,000	2001	2	Increasing
Scotland	**119,200**			
English North Sea coast	5,900	2000	2	Increasing
Southwest (England/Wales)	4,600	1999	1	Stable
England & Wales	**10,500**			
Total (UK)	**129,700**			
Ireland	2,000	1997-99	1	Unknown
Norway	3,000-3,500	1986	1	Unknown
Germany	71	1991	1	Increasing
The Netherlands	500	2000	1	Increasing
Baltic	12,053	2000	1	Increasing
Iceland	11,600	1987	1	
Faroes	4,000	1966	1	
Barents Sea	3,400	1990	1	
Europe (excluding UK)	**36,600**			
Canada	**173,500**	1998	2	Increasing
Total	**339,800**			

[1] 1 – Estimates based upon occasional pup counts
2 - Estimates based upon systematic annual pup counts using aerial survey

Table 2 Sizes and status of European populations of common seals.

Region	Population size[1]	Years when latest information was obtained	Status
Outer Hebrides	2,400	1996-2000	Possible increasing
Scottish W coast	14,200	1996-2000	Possible increasing
Scottish E coast	900	1996-97	Stable
Shetland	4,900	1996-2001	Possible decrease
Orkney	7,800	1996-2001	Possible decrease
Scotland	**30,200**		
England (E & S coast)	**4,400**	2001	Increasing
Northern Ireland	**400**	1997	Decrease since 1970s
UK (Total)	**35,000**		
Ireland	900	1978	
Wadden Sea (Germany)	11,500	2000	Increasing
Wadden Sea (Netherlands)	3,300	2000	Increasing
Wadden Sea (Denmark)	2,100	2000	Increasing
Limfjorden (Denmark)	1,000, 495	1998-2000	Decrease since 1998
Kattegat/Skagerrak	9,752	2000	Increasing
West Baltic	315	1998	Small increase
Kalmarsund (East Baltic)	270	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	660	?	Unknown
Europe (excluding UK)	**52,600**		
Total	**87,500**		

[1] – many of these estimates represent counts of seals. They should be considered as minimum estimates of total population size.

Pup Production in the British Grey Seal Population

Callan Duck

Sea Mammal Research Unity, Gatty Marine Laboratory, University of St Andrews

1. Surveys conducted in 2001

Each year SMRU conducts aerial surveys of the major grey seal breeding colonies in Britain to determine the number of pups born. In addition, new sites where grey seal pups have been reported or which appear to be suitable for colonisation are visited regularly. During 2001, between four and six surveys were flown over all the major sites in the Hebrides, Orkney and in the Firth of Forth. Ground counts of the numbers of pups born at the Farne Islands were made by National Trust staff. Similar counts at Donna Nook on the Humber Estuary were made by members of the Lincolnshire Wildlife Trust. Locations of the main British grey seal breeding sites are shown in Figure 1.

2. Estimated pup production

The number of pups born (pup production) at regularly surveyed colonies is estimated each year from counts from aerial survey photographs using a model of the birth process and the development of pups. The method used to obtain the estimates for this year's advice was similar to that used for the past several years.

Total pup production in 2001 at all annually surveyed sites is estimated to be 36,920 which is almost identical to the estimate for 2000 (36,915 pups). Estimates of the total pup production from all major breeding sites in England and Scotland (except Loch Eriboll, Helmsdale and Shetland) between 1984 and 2001 are shown in Figure 2. Pup production estimates for the main island groups (the Inner Hebrides, the Outer Hebrides and Orkney) are shown in Figure 3a and for the North Sea sites in Figure 3b. The time series of data for island groups are given in Table 1. For colonies not surveyed by air, pup numbers are counted directly on the ground either annually (Farne Islands and Donna Nook,) or less frequently (South Ronaldsay, SW England, Wales and Shetland).

3. Trends in pup production

Between 1984 and 1996 estimates of the total number of pups born at regularly surveyed colonies have increased year on year. In 1997, estimated pup production fell for the first time but recovered again in 1998 in line with the previously observed upward trend. However, there was a second temporary decline in 1999 followed by a recovery in 2000. Pup production remained nearly static between 2000 and 2001.

The differences between 2000 and 2001 are shown in Text-table 1. This shows that, while the percentage change between 2000 and 2001 varied from –10% at the Isle of May to +10% in Orkney, the overall pup production for the population as a whole was static between 2000 and 2001. There appears to be greater fluctuation in pup production within regions between years. For example, the change between 1999 and 2000 in the Outer Hebrides was +15% whereas the change in the past year for the same region was –8%. A similar pattern was observed for the Inner Hebrides, which had a similar magnitude of fluctuation to that of the Outer Hebrides suggesting that the fluctuations in the pup production in these two regions could be caused by the same process. Until 2001, fluctuations in

Orkney also followed a similar pattern to those in the Outer Hebrides. However, in 2001 pup production in the Outer Hebrides declined while it increased in Orkney.

The mean annual percentage change in pup production for each region is shown in Text-table 1. This shows that, apart form Donna Nook, which is the smallest of all the regional groups considered here with only 634 pups born in 2001, the mean annual change ranged from –2% to +4% and the annual change for the population as a whole was +2.8%

Text-table 1. The percentage change in grey seal pup production at annually surveyed colonies, between 2000 and 2001 with the mean annual change between 1997 and 2001.

Location	Change 2000-2001	Mean Change 1997-2001
Inner Hebrides	-8.8%	-0.5%
Outer Hebrides	-8.0%	+1.4%
Orkney	+9.6%	+4.4%
Isle of May + Fast Castle	-10.4%	+3.3%
Farne Islands	+6.5%	-1.7%
Donna Nook	+2.6%	+14.5%
Total	**0.0%**	**+2.8%**

The results from 2001 support the trends observed in recent years. First, pup production in the Hebrides has remained unchanged since 1992. Second, based upon the most recent count, there is now reduced evidence to support the suggestion of a slowing in the rate of increase in pup production in Orkney. Third, the North Sea colonies as a whole are showing a gradual overall decline in the rate of increase in pup production even though there has been a rapid increase at the small colony at Donna Nook on the Lincolnshire coast (Text-table 2). Overall, the trend in the rate of increase suggests a gradual decline has been taking place during the past 10 years. In the late 1980s, pup production was increasing at over 6% per annum and this had declined to 3% in the past 5 years.

Pup production fluctuates between years, but in the last 5 years the fluctuations have been larger than previously (Figure 2). This is also reflected in the annual rate of change between years (Annex IV, Figure 4). It is difficult to be sure what causes these changes but they could indicate that the population is nearing its limits of size. To even out these fluctuations the average percentage rate of annual change in the pup production by region is shown in Text-table 2 for the past 5 years and this probably provides the best indication of the current trend in pup production.

4. Pup production model assumptions

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

In the past versions of this advice, we have considered the effect of allowing the time-to-leave parameter to vary. However, although the pup production trajectory is slightly lower using the method with variable time-to-leave, the variations in pup production are consistent amongst the two methods. Since we are in the process of developing a new method for estimating pup production from production curves we will not present data using the method involving a variable time-to-leave.

This is consistent with the Advice provided in previous years.

Text-table 2. Pup production estimates for the main colonies surveyed in 2001. The annual changes over successive 5-year periods are also shown. These annual changes represent the exponential rate of change in the pup production. The total for the North Sea represents the estimates for the Isle of May, Fast Castle, Farne Islands and Donna Nook combined.

Location	2001 pup production	Annual change in pup production		
		1987-1991	1992-1996	1997-2001
Inner Hebrides	2,938	+4.2%	+2.5%	-0.5%
Outer Hebrides	12,325	+5.1%	+2.2%	+1.4%
Orkney	17,523	+7.4%	+9.6%	+4.4%
Isle of May + Fast Castle	2,253	+14.0%	+3.9%	+3.3%
Farne Islands	1,247	+2.1%	+1.7%	-1.7%
Donna Nook	634	+39.0%	+14.6%	+14.5%
Total (North Sea)	4,134	+9.6%	+4.0%	+3.0%
Total	36,920	+6.2%	+5.2%	+2.8%

6. Confidence limits

Ninety-five percent confidence limits on the pup production estimates at each site are within 14% of the point estimate. The exact limits depend on a number of factors including the number of surveys flown in a particular year. Confidence limits can be seen in Figures 3a (Orkney, Inner and Outer Hebrides) and 3b (Isle of May and Fast Castle only).

7. Pup production at sites surveyed less frequently

The total population associated with breeding sites not surveyed regularly has been calculated using the ratio of total population to pup production for the main areas. Less than 15% of all pups are born at these sites each year. Confidence limits cannot be calculated for these estimates because they are obtained by simple extrapolation of single counts. The resulting figures are given in Text-table 3.

Text-table 3. Pup production estimates for breeding sites not surveyed regularly

Region	Date and location of last survey	Pup production (to nearest 100)
Mainland Scotland & South Ronaldsay	Helmsdale (including Berriedale) 2001 Loch Eriboll 2000 South Ronaldsay 1998	1,800
Shetland	1977	1,000
Southwest Britain	Southwest England 1973 Wales 1994	1,500

Text-table 3 shows Scottish breeding sites which are either not surveyed annually or have recently been included in the survey programme. These and other potential breeding sites are checked when flying time, flying conditions and additional circumstances permit. Accumulated data from sites that are surveyed on an *ad hoc* basis are given in Table 2. Taking all these additional sites into account, about 5,000 pups are likely to be born at sites that are not part of the main annual survey.

Table 1. Estimates of pup production for the North Sea, Orkney, Outer Hebrides and Inner Hebrides, 1960-1999.

YEAR	North Sea	Orkney	Outer Hebrides	Inner Hebrides
1960	1020	2048		
1961	1141	1846	3142	
1962	1118			
1963	1259			
1964	1439	2048		
1965	1404	2191		
1966	1728	2287	3311	
1967	1779	2390	3265	
1968	1800	2570	3421	
1969	1919	2316		
1970	2002	2535	5070	
1971	2042	2766		
1972	1617		4933	
1973	1678	2581		
1974	1668	2700	6173	
1975	1617	2679	6946	
1976	1426	3247	7147	
1977	1243	3364		
1978	1162	3778	6243	
1979	1620	3971	6670	
1980	1617	4476	8026	

Table 1 continued.

YEAR	North Sea	Orkney	Outer Hebrides	Inner Hebrides
1981	1531	5064	8086	
1982	1637	5241	7763	
1983	1238			
1984	1325	4741	7594	1332
1985	1711	5199	8165	1190
1986	1834	5796	8455	1711
1987	1867	6389	8777	2002
1988	1474	5948	8689	1960
1989	1922	6773	9275	1956
1990	2278	6982	9801	2032
1991	2375	8412	10617	2411
1992	2437	9608	12215	2816
1993	2710	10790	11915	2923
1994	2652	11593	12054	2719
1995	2757	12412	12713	3050
1996	2938	14195	13176	3117
1997	3698	14051	11946	3076
1998	3989	16231	12373	3087
1999	3380	15253	11683	2787
2000	4303	15993	13396	3223
2001	4134	17523	12325	2938

Table 2. Scottish grey seal breeding sites that are not surveyed annually and/or have recently been included in the survey programme.

	Location	Survey method	Last surveyed, frequency	Number of pups
Inner Hebrides	Colonsay/Oronsay mainland	SMRU visual	2001, annual	94
	Loch Tarbert, Jura	SMRU visual	1998, every 3-4 years	None seen
	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	1999, 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	1998, every 2-3 years	13
	Muck	SMRU photo	1998, every other year	12
	Rum	SNH ground	2001, annual	10-15
	Canna	SMRU photo	1998, every other year	34
	Rona	SMRU visual	1989, infrequent	None seen
	Ascrib Islands, Skye	SMRU photo	1998, every other year	32
	Heisgeir, Dubh Artach, Skerryvore	SMRU visual	1995, every other year 1989, infrequent	None None
Outer Hebrides	Barra Islands Fiaray & Berneray	SMRU visual	2001, annual?	102
	Sound of Harris islands	SMRU photo	1999, every 2-3 years	317
	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 visual	1989, infrequent	None seen
	Faraid Head	SMRU visual	1989, infrequent	None seen
	Eilean Hoan, Loch Eriboll	SMRU visual	1998, annual	None
	Rabbit Island, Tongue	SMRU visual	1998, every other year	None seen
Orkney	Sule Skerry	SMRU photo	1998, 1999, 2000, 2001	15, 7, 7, 10
	Sanday, Point of Spurness	SMRU photo	1999, every 2-3 years	62
	Sanday, east and north	SMRU visual	1994, every 2-3 years	None seen
	Papa Stronsay	SMRU visual	1993, every 3-4 years	None seen
	Holm of Papa, Westray	SMRU visual	1993, every 3-4 years	None seen
	North Ronaldsay	SMRU visual	1994, every 2-3 years	None seen
	Eday mainland	SMRU photo	2000, first	8
	Calf of Flotta	SMRU photo	2000, annual	250
	South Fara, Cava & Rysa	SMRU photo	2000, annual	155
Others	Firth of Forth islands & Inchcolm	Anecdotal SMRU photo	Infrequent 1997	<10 4

Figure 1 Map of the UK showing the locations of grey seal breeding colonies

Figure 2. Total estimated pup production for all major breeding colonies in Scotland and England (excluding Loch Eriboll, Helmsdale and Shetland) from 1984 to 2001.

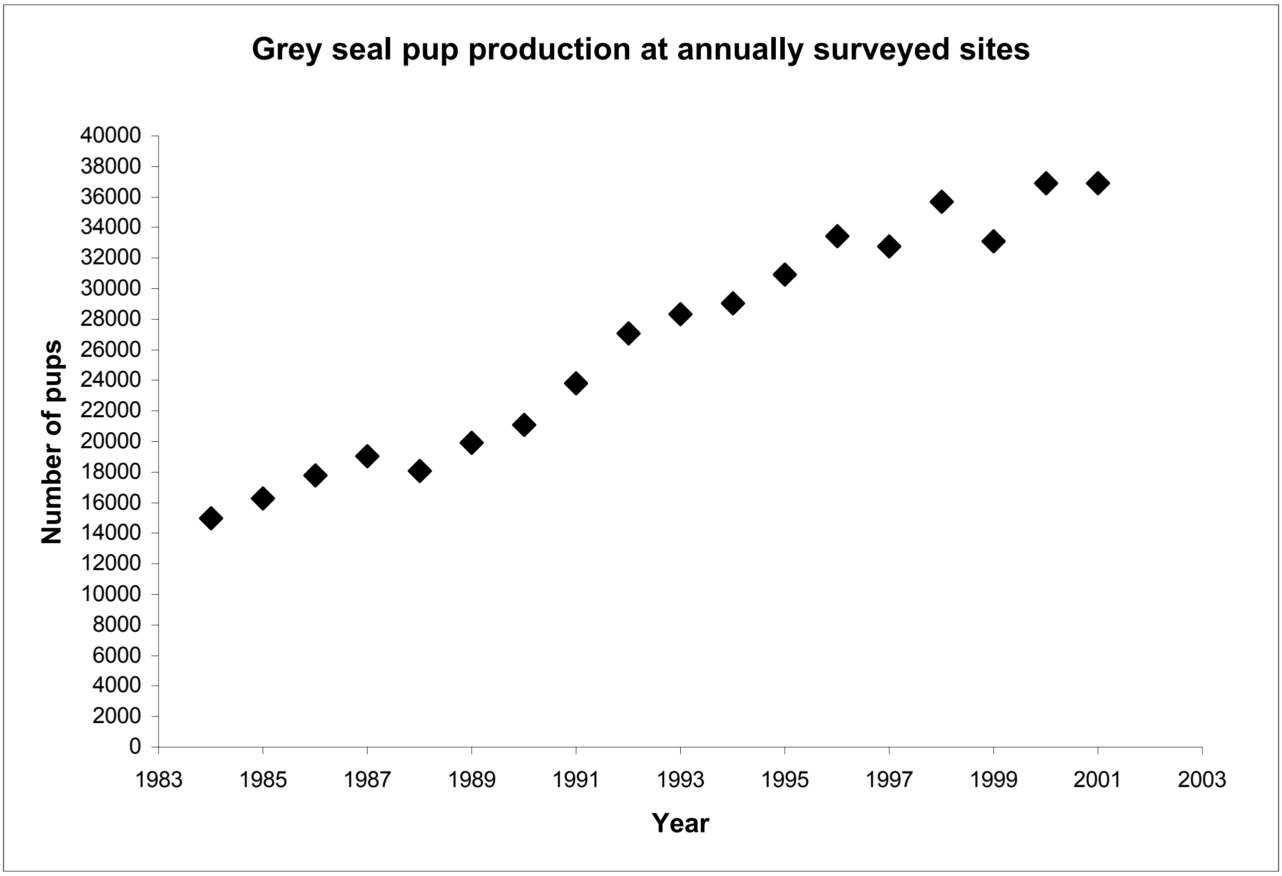
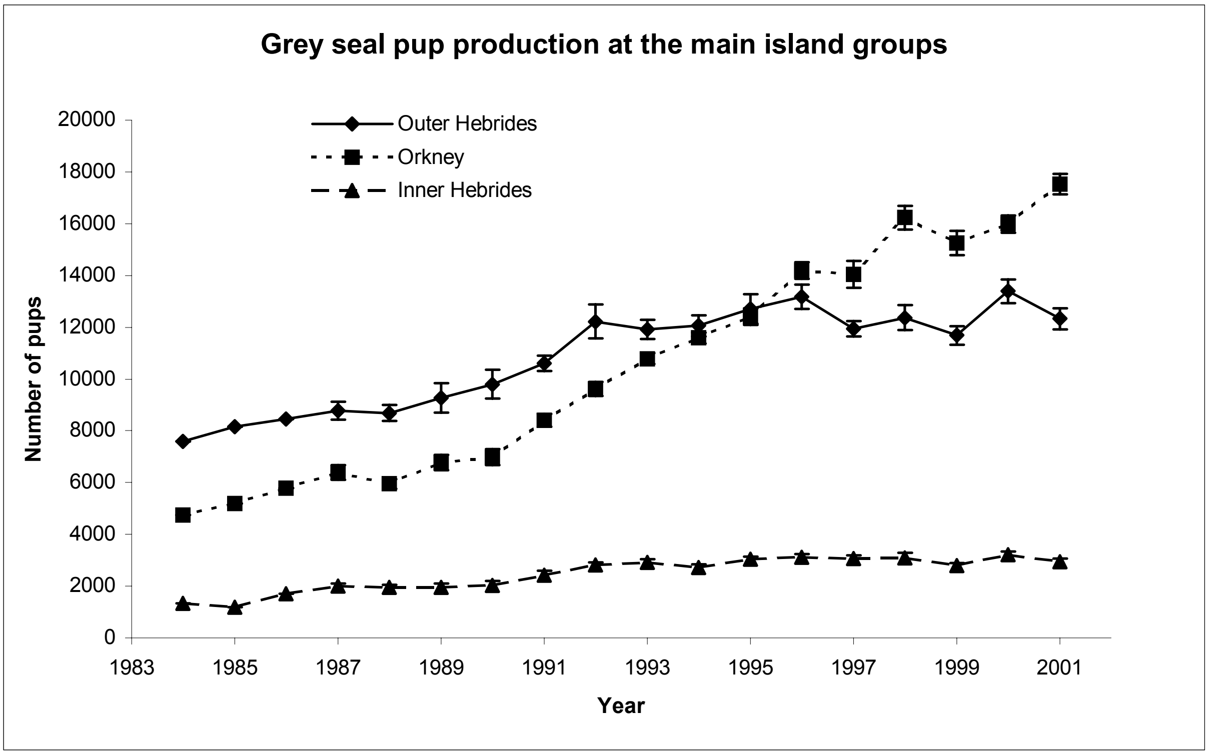
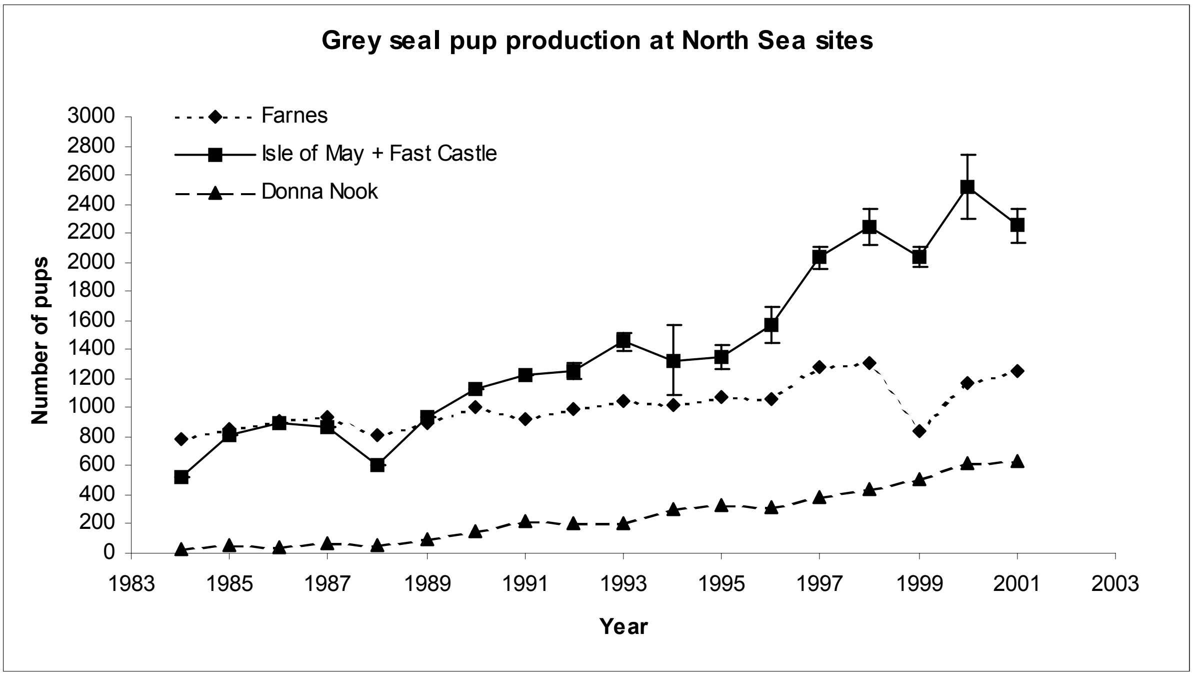


Figure 3 Trends in pup production at the major grey seal breeding areas since 1984. Production values are shown with their upper and lower 95% confidence limits where these are available. These limits assume that the various pup development parameters which are involved in the estimation procedure remain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

(a) Outer Hebrides, Orkney and Inner Hebrides



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



Estimates of pup production

Table 1. Pup production estimates for islands in the Inner Hebrides group

YEAR	Gunna	Northern Treshnish	Fladda	Sgeir a' Chaisteil & Eirionnach	Lunga	Soa	Eilean nan Ron	Eilean nan Eoin	Nave Island	TOTAL
1984	206	87	169	136	226	63	180	190	75	1332
1985	192	84	109	113	136	63	158	269	66	1190
1986	263	114	149	119	204	111	302	305	144	1711
1987	361	115	194	147	234	102	420	297	132	2002
1988	332	130	231	170	246	102	389	225	135	1960
1989	347	131	234	187	277	101	308	167	204	1956
1990	342	146	183	162	221	107	392	265	214	2032
1991	475	125	288	174	271	97	409	377	195	2411
1992	527	203	347	153	341	98	453	438	256	2816
1993	514	211	324	186	385	91	464	458	290	2923
1994	580	145	280	148	356	96	349	456	309	2719
1995	541	181	368	182	429	116	454	440	339	3050
1996	583	181	351	186	414	92	558	431	321	3117
1997	589	158	365	177	448	81	562	414	282	3076
1998	638	168	315	166	427	63	490	430	390	3087
1999	522	158	319	173	352	57	481	392	333	2787
2000	625	177	355	167	392	82	617	406	402	3223
2001	615	171	295	141	350	74	515	405	372	2938

Table 2. Pup production estimates for islands in the Outer Hebrides group

YEAR	Gasker	Coppay	Shillay (Sound of Harris)	Haskier	Causamul	Deasker	Shivinish (Monachs)	Ceann Iar (Monachs)	Ceann Ear (Monachs)	Shillay (Monachs)	Stockay (Monachs)	Monachs total	Others	North Rona	TOTAL
1960															
1961	847	62	120	81	67	13						0	0	1949	3142
1962															
1963															
1964															
1965															
1966	1084	230	120	96	242	0	0					38	0	1499	3311
1967	1084	153	80	96	161	0	0					114	0	1574	3265
1968	1084	115	161	96	161	0	0					152	0	1650	3421
1969															
1970	1129	324	714	130	103	41	0	0	84	60	460	605	0	2023	5070
1971															
1972	1141	316	605	167	271	67	0	0	274	49	730	1054	0	1309	4933
1973															
1974	1756	286	692	176	224	83	0	49	459	44	754	1307	0	1647	6173
1975	1538	367	631	212	202	51	0	141	690	217	932	1982	0	1961	6946
1976	1813	394	553	278	217	57	0	111	628	152	1053	1946	0	1886	7147
1977															
1978	1101	321	508	320	172	51	0	560	371	205	626	1764	0	2002	6243
1979	992	377	546	269	159	80	0	672	810	164	826	2474	0	1770	6670
1980	1345	462	794	351	163	31	0	1077	880	242	647	2848	162	1867	8026

Table 2 (continued). Pup production estimates for islands in the Outer Hebrides group

YEAR	Gasker	Coppay	Shillay (Sound of Harris)	Haskier	Causamul	Deasker	Shivinish (Monachs)	Ceann Iar (Monachs)	Ceann Ear (Monachs)	Shillay (Monachs)	Stockay (Monachs)	Monachs total	Others	North Rona	TOTAL
1981	1255	423	1016	278	178	68	0	1279	486	331	847	2944	136	1785	8086
1982	1443	634	219	322	260	110	0	1329	557	199	712	2798	85	1888	7763
1983															
1984	1120	389	386	277	143	0	83	2175	616	209	555	3638	0	1641	7594
1985	1303	408	335	254	168	0	261	2365	748	193	641	4208	0	1489	8165
1986	1258	378	356	225	108	0	283	2931	822	222	572	4830	0	1300	8455
1987	1337	393	365	224	131	0	353	3227	666	223	670	5139	0	1188	8777
1988	1205	354	372	195	122	0	429	3733	418	189	579	5348	0	1093	8689
1989	1294	383	348	176	73	0	512	4041	518	212	535	5818	0	1183	9275
1990	1398	396	321	146	115	0	574	4554	510	174	457	6269	0	1156	9801
1991	1406	440	334	159	94	0	582	5098	543	181	494	6898	0	1286	10617
1992	1527	427	514	179	91	0	576	5852	716	204	599	7947	0	1530	12215
1993	1525	366	431	150	107	0	640	5498	1037	192	524	7891	0	1445	11915
1994	1432	394	491	123	86	0	640	5956	921	196	522	8235	0	1293	12054
1995	1389	392	570	120	55	0	856	6332	977	200	480	8845	0	1342	12713
1996	1508	391	574	133	64	0	721	6648	1254	157	445	9225	0	1281	13176
1997	1301	303	470	79	67	0	795	5660	1656	76	458	8645	0	1081	11946
1998	1444	307	552	90	64	0	865	5711	1649	70	422	8717	0	1199	12373
1999	1247	224	508	66	45	0	739	5637	1514	69	464	8423	0	1170	11683
2000	1388	212	519	80	48	0	834	6439	2199	129	443	10044	0	1105	13396
2001	1251	206	492	79	35	0	771	5724	2110	138	473	9216	0	1046	12325

Table 3. Pup production estimates for islands in the Orkney group

YEAR	Muckle Green-holm	Little Green-holm	Little Linga	Holm of Spur-ness	Point of Spur-ness	Linga-holm	Holm of Huip	Fara-holm	Faray	Rusk-holm	Wart-holm	Sweyn-holm & Gairsay	Grass-holm	Swona	Pent-land Skerry	Aus-kerry	Switha	Stroma	Calf of Eday	Copin-say	Stron-say	TOTAL
1960	734	190	239	90	0	0	0	441	0	208	41	0	0	2	98	0	0	0	0	0	0	2048
1961	537	290	251	124	0	0	0	300	0	256	33	0	0	2	48	0	0	0	0	0	0	1846
1962	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
1963	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
1964	934	469	154	25	0	0	0	22	117	208	16	55	3	14	24	0	0	0	0	0	0	2048
1965	671	366	279	138	0	0	0	113	151	247	29	21	66	19	85	0	0	0	0	0	0	2191
1966	688	454	344	138	0	0	0	270	154	87	8	59	18	14	48	0	0	0	0	0	0	2287
1967	600	445	395	98	0	0	0	270	165	252	8	111	0	6	36	0	0	0	0	0	0	2390
1968	650	310	399	278	0	13	0	257	258	195	8	81	36	27	52	0	0	0	0	0	0	2570
1969	567	298	576	189	8	28	0	214	28	208	4	77	59	35	20	0	0	0	0	0	0	2316
1970	747	318	519	135	45	42	22	171	95	223	4	13	66	43	85	0	0	0	0	0	0	2535
1971	588	351	708	158	49	137	30	320	88	103	16	70	40	67	36	0	0	0	0	0	0	2766
1972	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
1973	503	207	519	233	66	177	88	351	35	15	12	86	92	51	52	87	0	0	0	0	0	2581
1974	525	190	479	146	21	61	137	500	72	132	0	134	69	71	73	84	0	0	0	0	0	2700
1975	483	230	483	271	49	39	117	477	65	63	4	111	21	59	48	152	0	0	0	0	0	2679
1976	605	175	648	328	53	68	68	398	85	60	4	198	21	92	65	375	0	0	0	0	0	3247
1977	679	210	684	305	78	50	130	477	58	111	4	194	21	92	65	199	0	0	0	0	0	3364
1978	333	210	800	471	136	79	192	700	58	219	4	149	36	104	57	134	0	90	0	0	0	3778
1979	546	294	344	430	127	144	368	672	92	280	4	142	69	92	65	145	0	152	0	0	0	3971
1980	496	166	676	415	107	315	275	817	165	336	0	167	74	108	81	97	0	174	0	0	0	4476
1981	442	199	860	449	45	293	510	712	202	319	4	108	92	225	125	249	0	223	0	0	0	5064

Table 3 (continued). Pup production estimates for islands in the Orkney group

YEAR	Muckle Green-holm	Little Green -holm	Little Linga	Holm of Spur-ness	Point of Spur-ness	Linga-holm	Holm of Huip	Fara-holm	Faray	Rusk-holm	Wart-holm	Sweyn-holm & Gairsay	Grass-holm	Swona	Pent-land Skerry	Aus-kerry	Switha	Stroma	Calf of Eday	Copin-say	Stron-say	TOTAL
1982	454	87	716	665	29	326	521	817	146	295	4	104	103	148	147	294	153	227	0	0	0	5241
1983	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
1984	517	127	601	518	0	303	368	834	376	335	0	111	79	85	70	219	119	79	0	0	0	4741
1985	483	191	568	643	0	342	245	796	526	315	0	115	60	260	82	261	151	161	0	0	0	5199
1986	637	227	602	533	0	390	358	752	811	345	0	145	81	191	70	278	157	219	0	0	0	5796
1987	592	231	678	570	0	502	548	837	910	261	0	109	83	327	90	216	153	282	0	0	0	6389
1988	393	181	590	424	0	569	557	833	921	247	0	135	66	336	62	222	167	245	0	0	0	5948
1989	426	191	574	426	0	696	638	760	1452	232	0	164	48	314	62	279	207	304	0	0	0	6773
1990	334	201	625	341	0	807	731	970	1313	179	0	195	49	351	79	252	206	349	0	0	0	6982
1991	459	186	728	388	0	1144	880	976	1602	192	0	214	70	514	96	277	272	414	0	0	0	8412
1992	507	222	845	462	0	1186	1052	1304	1845	204	0	223	56	585	51	206	304	556	0	0	0	9608
1993	601	241	830	385	0	1249	1221	1325	1781	218	0	292	88	604	86	166	324	595	270	514	0	10790
1994	642	262	786	348	0	1527	1294	1238	1909	220	0	272	69	674	65	161	331	508	346	795	146	11593
1995	728	300	795	420	0	2128	887	1387	2136	251	0	461	32	578	71	125	442	339	274	940	118	12412
1996	770	289	834	416	0	2255	1349	1464	1935	243	0	518	64	829	79	123	370	583	399	1480	195	14195
1997	786	332	771	387	0	2294	1071	1464	2024	215	0	336	46	870	66	131	347	638	587	1455	231	14051
1998	883	442	842	429	0	2583	1323	1675	2166	272	0	405	61	1032	69	123	430	784	499	1914	299	16231
1999	790	438	632	449	0	2390	1240	1399	2152	220	0	505	40	957	62	44	449	686	567	1962	271	15253
2000	898	367	704	419	0	2890	1347	1293	2061	191	0	482	22	1005	60	54	474	826	456	2082	362	15993
2001	1000	427	723	482		3156	1402	1291	2168	239		563	26	1077	55	58	441	1091	556	2540	300	17523

Table 4. Pup production estimates for other sites routinely monitored.

YEAR	Farne Islands	Isle of May	Fast Castle	SW Eng-land	Wales	Donna Nook	Helms-dale	Loch Eriboll	E. nan Ron, Tongue	Shet-land	S. Ron-aldsay (Orkney)
1956	751	.	.	.	.	.	.	.	.	.	.
1957	854	.	.	.	.	.	.	.	.	.	.
1958	869	.	.	.	.	.	.	.	.	.	.
1959	898	.	.	.	.	.	.	.	.	.	.
1960	1020	.	.	.	.	.	.	.	.	.	123
1961	1141	.	.	.	.	.	.	.	.	.	152
1962	1118	.	.	.	.	.	.	.	.	.	.
1963	1259	.	.	.			.	.	.	.	.
1964	1439	.	.	.	.	.	.	.	.	.	115
1965	1404	.	.	.	.	.	.	.	.	.	74
1966	1728	.	.	.	.	.	.	.	.	.	107
1967	1779	.	.	.	.	.	.	.	.	.	132
1968	1800	.	.	.	.	.	.	.	.	.	152
1969	1919	.	.	.	.	.	.	.	.	.	127
1970	1987	.	.	.	.	15	.	.	.	.	103
1971	2041	.	.	.	.	1	.	.	.	.	148
1972	1617	.	.	.	.	0	.	.	.	.	.
1973	1678	.	.	107	.	0	.	.	.	578	123
1974	1668	.	.	.	.	.	.	.	.	.	136
1975	1617	.	.	.	.	.	.	.	.	.	197
1976	1426	.	.	.	.	.	.	.	.	.	160
1977	1243	.	.	.	645	.	.	.	.	700	156
1978	1162	.	.	.	.	.	.	.	.	.	169
1979	1320	300	.	.	.	.	.	.	.	.	164
1980	1118	499	.	.	.	.	.	.	.	.	140
1981	992	505	.	.	.	34	.	.	.	.	82
1982	991	603	.	.	.	43	.	.	.	.	103

Table 4 continued. Pup production estimates for other sites routinely monitored.

YEAR	Farne Islands	Isle of May	Fast Castle	SW Eng-land	Wales	Donna Nook	Helms-dale	Loch Eriboll	E. nan Ron, Tongue	Shet-land	S. Ron-aldsay (Orkney)
1983	902	336	.	.	.	.	.	.	.		.
1984	778	517	.	.	.	30	94	406	.	.	.
1985	848	810	.	.	.	53	.	.	.	.	.
1986	908	891	.	.	.	35	.	.	.	.	.
1987	930	865	.	.	.	72	.	.	.	.	.
1988	812	608	.	.	.	54	.	.	.	.	.
1989	892	936	.	.	.	94	280	666	.	.	.
1990	1004	1122	.	.	.	152	.	.	.	.	.
1991	927	1225	.	.	.	223	321	.	.	.	241
1992	985	1251		.	1308	200	225	612	.	.	246
1993	1051	1454		.	1372	205	.	700	.	.	244
1994	1025	1325		.	1350	302	.	700	.	.	258
1995	1070	1353		.	.	334	300	516	.	.	250
1996	1061	1567		.	.	310	300	726	.	.	250
1997	1284	1796	236	.	.	382	523*”	719	.	.	250
1998	1309	1968	273	.	.	439	.	649	200	.	250
1999	843	1766	268	.	.	503	.	(422)”	(83)”	.	.
2000	1171	2133	381	.	.	618	.	670	235	.	.
2001	1247	1932	321	.	.	634	676*”	.	.	.	.

* Includes pups on Berridale beaches.
” One flight only

The Status of British Common Seal Populations

Callan Duck & Dave Thompson

1. Common seals surveys in eastern England 2001

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).

One complete aerial survey of common seals was carried out in Lincolnshire and Norfolk during August 2001 (Table 1). The count for The Wash (3194) was the highest ever recorded. It was 15% greater than the mean of the 2000 counts (2,778) and 5% greater than the higher of the 2000 counts (3029). The average annual rate of increase in the number of seals counted in The Wash since 1989 is 6.3% (SE = 0.60%). This is significantly greater than the average annual rate of increase between 1968 and 1988 of 3.5% (SE = 0.29%).

The 2001 count of common seals in The Wash exceeded the 1988 pre-epidemic count by 5%. It has taken 13 years for the population to recover from the effects of the PDV epidemic. This is in contrast to populations on the east and south sides of the North Sea, which recovered more rapidly and were similar to or exceeded their pre-epidemic levels by 1996. The 2001 counts at Blakeney Point and Donna Nook were lower than those in 2000 (Table 1), by 14% and 40% respectively. However, the average annual rates of increase in the number of seals counted at these sites since 1989 (16% (SE=3%) and 20% (SE=4%) respectively) are higher than in The Wash. Overall, the English East coast population has been increasing at an average annual rate of 7.4% (SE=0.5%).

2. Common seals in Scotland

In August 2001, the coasts of Orkney and Shetland were surveyed for common seals. These are part of the third round Scotland survey and were part funded by Scottish Natural Heritage. The 2001 counts for both areas were lower than the two most recent previous counts in 1993 and 1997. In Shetland the 2001 count was 18.5% lower than the 1997 count and in Orkney the count was 9% lower. However, counts in both these regions lay within the range of the counts made since 1989. Other data for the University of Aberdeen has shown declines in common seal abundance in some areas of Orkney.

Location	**1989**	**1991**	**1993**	**1997**	**2001**
Orkney	7137		7873	8523	7752
Shetland		4794	6224	5991	4883

3. Minimum estimate of the British common seal population

The most recent minimum estimate of the number of common seals in Scotland is 30,196 from surveys carried out in 1996, 1997, 2000 and 2001. The most recent minimum estimate for England is 4,409. This comprises 4,274 seals in Lincolnshire and Norfolk in 2001 plus 135 seals in Northumberland, Cleveland, Essex and Kent between 1994 and 1997 and an estimated 20 seals from the south and west coasts.

Counts by region are given in the Table below for the periods 1996-1997 and 1996-2001. These are presented as the most recent counts for each region during the specified period. Where multiple counts were obtained in the most recent surveys, the mean values are presented.

Region	1996-2001
Shetland	4,883
Orkney	7,752
Outer Hebrides	2,413
Highland (Nairn to Appin)	6,291
Strathclyde (Appin, Loch Linnhe to Loch Ryan)	7,909
Dumfries & Galloway (Loch Ryan to English Border at Carlisle)	6
Grampian (Montrose to Nairn)	126
Tayside (Newburgh to Montrose)	165
Fife (Kincardine Bridge to Newburgh)	611
Lothian (Torness Power Station to Kincardine Bridge)	40
Borders (Berwick upon Tweed to Torness Power Station)	0
TOTAL SCOTLAND	**30,196**
Blakney Point	772
The Wash	3,194
Donna Nook	233
Scroby Sands	75
Other east coast sites	135
South and west England (estimated)	20
TOTAL ENGLAND	**4,429**
TOTAL BRITAIN	**34,625**

4. Common seal surveys proposed for 2002

Common seals in the Outer Hebrides, Northern Island and on the east coast between the Moray Firth and Thames estuaries will be surveyed in August 2002. The outbreak of a new PDV epidemic in the southern Baltic and Waddensee populations in 2002 makes it imperative that the whole of the East coast of the UK is surveyed in advance of any large scale mortality. These surveys will be part funded by SNH, Northern Ireland Office and DEFRA and these surveys have been completed

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	11.8.90	2.8.91 11.8.91	1.8.92 16.8.92	8.8.93	6.8.94 12.8.94	5.8.95 15.8.95	2.8.96	2.8.97 8.8.97	7.8.98 14.8.98	3.8.99 13.8.99	4.8. 00 12.8.00	4.8.01
Blakeney Point	701	- 307	73	- -	- 217	267	- 196	438 392	372	250 371	535 738	715 602	895 dist.	772
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
Donna Nook	173	- 126	57	- -	18 -	88	60 146	115 36	162	240 262	294 201	321 286	435 345	233
Scroby Sands	-	- -	-	- -	- -	-	61 -	- 49	51	58 72	52 -	69 74	84 9	75
The Tees	-	- -	-	- -	- -	-	- 35	- -	-	- -	- -	- -	- -	-
Holy Island (Northumberland)	-	- -	-	- -	- -	-	- 13	- -	-	- 12	- -	- -	- 10	-
Essex & Kent	-	- -	-	- -	- -	-	- -	90 -	-	- -	- -	- -	- -	-

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

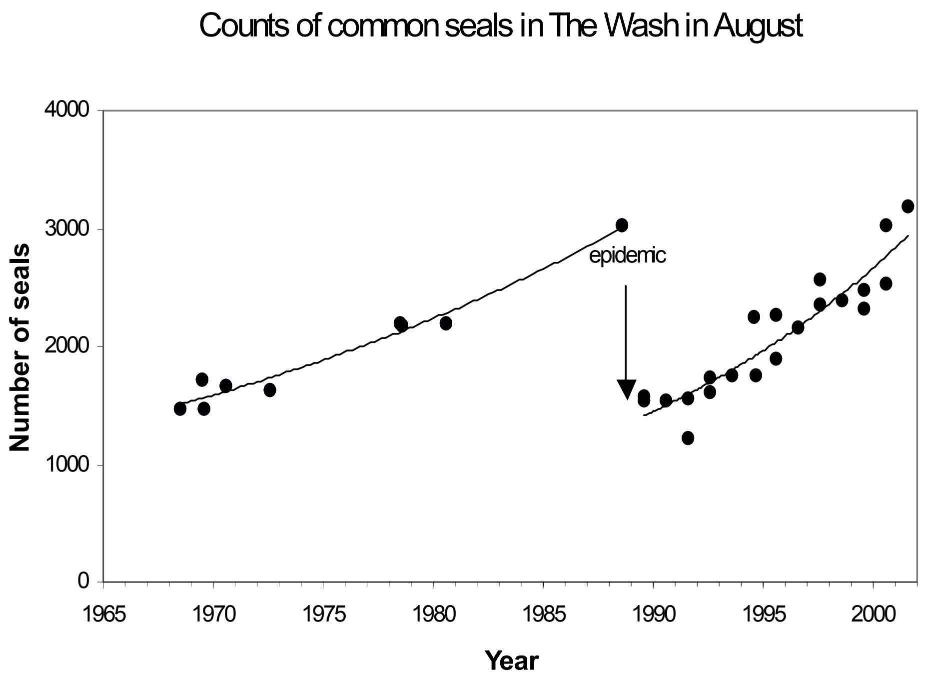


Figure 1. Counts of common seals in The Wash in August. These data are an index of the population size through time.

Population dynamics of grey seals

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Introduction

The management of the UK grey seal population requires the development of robust models of the underlying processes driving the dynamics of the population. Grey seal population dynamics do not differ fundamentally from those of other wildlife populations in terms of the underlying processes of birth, death, immigration and emigration. The uniqueness of the problem associated with grey seal populations comes in terms of the detailed features of the uncertainty surrounding the vital rates and the data that is available to allow an assessment of the quality of the model.

Apart from the need to develop a population dynamics model as a management tool for grey seals in the UK, there is a requirement to derive an estimate of total population size for grey seals from the annual measures of pup production obtained from aerial surveys of the major breeding colonies. At its simplest level, this could be done by applying a simple multiplier to the pup production based upon our knowledge of the equilibrium age structure. For some purposes this could be a defensible approach but where there is the possibility of defining age structures with greater accuracy then it would appear to be reasonable to use these to increase the accuracy of estimates of total population size.

The recent operational model of the UK grey seal population (Hiby & Duck in press) had specific characteristics that made it difficult to implement in a contemporary context. It was not designed to cope with a population that was showing density-dependent changes and it was not formulated to examine changes at the level of sub-sections of the UK population. Recent data from estimates of pup production (SCOS 2002) suggest that density-dependent processes may be operating in some parts of the population. In addition, staff changes at SMRU mean that this model can no longer be supported as an interactive tool that can be used to address the requests for advice from the Scottish Executive. These requests have placed greater emphasis on future trends in the populations which the model was not formulated to provide.

Two new approaches have been taken at SMRU. These are conceptually similar but differ in their statistical rigour. The more rigourous approach, which is spatially explicit and will eventually operate at the level of individual colonies, includes density-dependence as a factor affecting juvenile survival. This approach is described in the accompanying information paper (Newman *et al. SCOS* 2002). The intention is to develop the model described by Newman *et al*. (SCOS 2002, Annex V) as the main population dynamics model for grey seals. However, this requires further work and, for the purpose of the present advice from SCOS we will retain the output from the Hiby & Duck model.

The second approach, which is outlined here mainly as an illustration, considers each of the four main regions of the UK grey seal population as separate entities and attempts to simulate the pup production trajectory in each of these from simple prior distributions of vital demographic rates. However, both approaches suffer from the same inherent uncertainties in the empirical data and from the fact that pup production alone is insufficient to provide robust estimates of all demographic variables. An objective of this paper is to describe these uncertainties and their possible consequences.

Data sources

Estimates of pup production in the UK grey seal population are mainly obtained from annual aerial surveys of all the main breeding sites. The methods and results are described in SCOS 2002 ANNEX II. Many of the estimates of vital rates in UK grey seals derive from studies carried out in the 1970s and 1980s.

Survival rates for adult grey seals have been estimated using data from adult female grey seals culled as breeding animals at the Farne Islands during 1972 and 1975 (Harwood & Prime 1978). The age structure of these animals suggested a mean annual survival rate of 0.94. Subsequent samples of grey seals from both the Hebrides and, outside the breeding season in the North Sea (Boyd 1982) supported a relatively high survival rate because of the regular presence of seals that were 30+ years of age.

Juvenile survival rates have been more difficult to estimate. Harwood and Prime (1978) derived these for grey seals at the Farne Islands by balancing the pup production with the adult age structure and productivity. They concluded that post-weaning first year survival was likely to be about 0.66. Subsequently, Hall *et al*. (2001) used mark-recapture analysis to provide an estimate of 0.62 (SEM=0.155) for the same parameter in females and 0.19 (SEM=0.084) in males of mean mass or condition at weaning.

Fecundity rate could not be estimated from seals shot at breeding colonies during the 1970s because these were, by definition, already breeding. A subsequent sample of seals mainly from the Farne Islands taken outside the breeding season during the early 1980s provided an estimated pregnancy rate of 0.94 amongst sexually mature adult females and showed that sexual maturity occurred mainly at age 5 with a range from 3 to 7 years of age (Boyd 1985). However, a sample from the Hebrides obtained in 1978 gave a pregnancy rate of 0.83. More recent longitudinal mark-recapture studies at North Rona (Pomeroy *et al.* 1999) gave a natality rate of 0.80-0.97 amongst a group of females that were breeding regularly between 1979 and 1995 at North Rona (Hebrides).

These estimates are similar to those used for examining grey seal population dynamics in the western Atlantic (Mohn & Bowen 1996).

Uncertainties associated with estimations of vital rates

The uncertainty in the estimates of pregnancy rate based upon mark-recapture studies (Pomeroy *et al*. 1999) was similar to that for estimates obtained from cross-sectional sampling (Boyd 1985). The true fecundity rate probably lies between 0.80 and 0.95, although as suggested by Boyd(1985) it is possible that some sampling regimes over-estimate fecundity so there could be an upward bias associated with some current estimates of fecundity.

The results of Hall *et al*.'s analysis (2001) suggest that the first year survival rate of females could be in the range 0.3-0.9.

Overall, the empirical estimates of the vital rates of the UK grey seal populations suggest a degree of consistency between studies. In addition, they are consistent with the dynamics of a population that has been increasing at the rates observed during the past 30 years. However, there are few quantitative data about how density-dependence influences these vital rates and there are also few data, beyond anecdotal observations, to quantify the contribution of movement of grey seals between different regions. Hall *et al*. (2001) showed that first year survival was a function of the condition of pups at weaning which is, in turn, a function of maternal condition (Pomeroy *et al*. 1999). This suggests that first year survival should be responsive to the amount of food available to mothers in the previous year. Therefore, there is some evidence that both first year survival and fecundity will have a density-dependent component depending upon food availability. It has not been possible to determine the extent to which post-first year survival is density-dependent. In addition, we cannot say what the relative sensitivity to density will be amongst these vital rates or what measure of density is likely to be most important. Newman *et al*. (SCOS 2002) have investigate the effects of density dependent first year survival and recruitment to the local breeding population.

Despite the internal consistency in the empirical measures of the vital rates, there is insufficient precision in these to allow investigation of the processes underlying the spatial and temporal variations currently observed in pup production or to investigate how these relate to total population size.

Density dependence: uncertainties and their consequences

There is almost no information about how the vital rates respond to density in the UK grey seal population. Dispersal appears to occur as a function of density, at least on a local scale (Boyd 2002, Gaggiotti *et al*. 2002), and as a result of disturbance (see later) but it is not clear how much dispersal occurs between the regions of the population and how much this is driven by local density. For the purpose of this analysis, dispersal is assumed to be insignificant or, if it does occur, it is assumed that it will be contained within the variability in survival rate.

The way in which density-dependence is factored into the assessment of grey seal population dynamics will influence the interpretation of the total population size derived from the estimates of pup production. This sensitivity is illustrated in Figure 1a. This shows that if changes in pup production are the result of adjustments in the fecundity rate then the estimated total population is considerably larger than if it is the result of changes in survival rates. The illustration in Figure 1a is for the Outer Hebrides and this shows that the total female population could be 30-40% larger if fecundity rather than survival are responsible for changes in the observed pup production.

An additional feature of the population if it is controlled only by changes in fecundity is that it takes a very long time to stabilise after pup production has stabilised. This is illustrated in Figure 1b where the pup production for the Outer Hebrides population has been held at 2001 levels until 2015. Even after this time, the adult female population continues to increase, albeit at a slower rate than before.

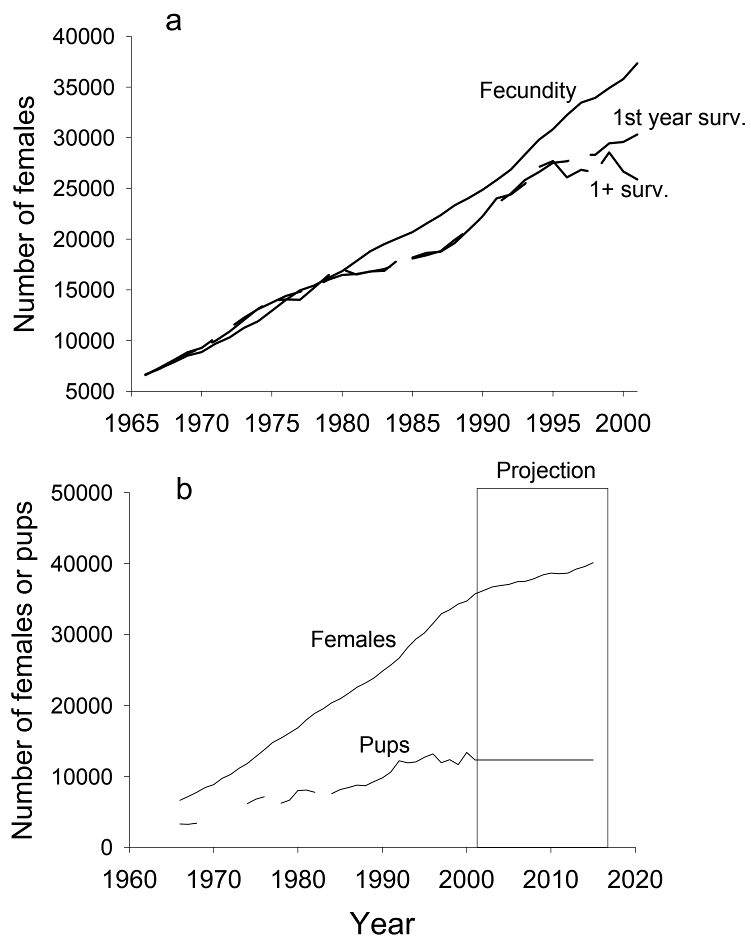

Figure 1. Investigation of the effects of uncertainty in which demographic variable is responsible for regulating the population. (a) Illustration of the effects of incorporating density dependence in different vital rates on total population size. The figure illustrates the data from the Outer Hebrides. (b) Pup production and total female population for the Outer Hebrides projected forward through time. The pup production has been held constant at 2001 levels after 2001.

Stochastic simulation of the population

Consequently, the largest problems faced when modelling the UK grey seal population are the uncertainties within the vital rates and, consequently, also in the starting age structure. The approach described here attempts to use the time-series of pup productions as a way of exploring the distribution of the vital demographic rates and, therefore, the age structure.

One approach to simulating the UK grey seal population is to develop a stochastic model that, as far as possible, relaxes assumptions about the precision with which the vital rates and starting age structure are known but which makes maximum use of the estimates of pup production which are the most precisely known population variables.

This approach considers the UK grey seal population as 4 independent spatial units, Inner Hebrides, Outer Hebrides, Orkney and North Sea and movement between these is assumed to be insignificant. A fully spatially explicit model is described briefly in the accompanying information paper (Harwood & Newman SCOS 2002). For the purpose of the present simulation, however, the aim is to find the combination of fecundity rate, first year survival rate and post-first year survival rate that explain the variation in pup production. This simulation makes no explicit attempt to model the density-dependent process because this should be an emergent property of the simulation. Although the three vital rates being modelled are partly confounded, their effects can be partially disentangled by fitting each to several years' pup production . Each demographic variable has a different effect upon the trajectory of the pup production, especially given the underlying history of the population expressed in the form of the age structure. Therefore, in order to fit to the pup production, there will be a most likely combination of fecundity, first year survival and post-first year survival that explains the trajectory of the pup production.

Critical tests for this approach are whether, overall, it settles upon estimates of the three vital rates being considered that are consistent with the empirical observation and whether it is able to resolve specific events in the management history of grey seals at the Farne Islands. In particular, this includes culls targeted on breeding adult females during 1972 and 1975.

Implementation of the simulation

The study was constructed as a Leslie matrix simulation. The fecundity rate, first year survival rate and post-first year survival rates were given prior distributions that were uniform. The only constraints on these distributions were that fecundity rates (female pups per adult female) were <0.5 and survival rates were <0.98. Age at sexual maturity was fixed at 5 years with a standard deviation of 0.25 years. The initial age structure was estimated using vital rates drawn from these uniform distributions and the modelled pup production for the population was allowed to converge with the starting pup production measured during the first survey in the time-series for each population.

Multiple projections (10,000) of the population were then carried out for each starting age structure based upon the prior distributions of the vital rates. The simulation process involved stepping forward through the pup production estimates seeking the maximum likelihood values for the three vital rates at each step. Maximum likelihood was estimated based upon the fit to the pup productions for the following 5 years with the highest weights given to the current and most recent years. This helped the simulation to distinguish changes in pup production caused by changes in post-first year survival from changes in first year survival or fecundity.

Testing the simulation

A critical test of the simulation as a method of investigating the changes occurring in vital rates is whether it is able to detect the occurrence of the culls that took place in the Farne Islands population during the 1970s and to represent these as changes in the adult female survival rate. The main culls that occurred took place in 1972 when 554 breeding females were killed and then in 1975 when 482 breeding females were killed. A further 92 females, most of which were adults, were killed outside the breeding season between during 1979 and 1981.

As can be seen from Figure 2, all these events are detectable in some form in the post-first year survival rate (Figure 2). There was an overall decline in post-first year survival between 1971 and 1978 with particularly low levels of survival in 1971 and 1975. It is not clear why the cull that took place in 1972 is represented in the estimate for 1971. However both events show declines in the survival rate of about 0.1. There were about 4000 females in the population at the time (Fig. 2) which gave an added component of mortality to females of 0.12. The decline in the survival rate derived by the simulation is, therefore, close to the expected level.

In addition, management at the Farne Island through the 1980s involved disturbing females that attempted to pup on specific islands. This may account for the reduce fecundity rate during the 1980s. Disturbance due to the culls in the 1970s may also have led to the reduced apparent survival rate during this time. In fact, some of this may have occurred as emigration. For example, the grey seal colony on the Isle of May was established at this time and some individuals may have moved even further.

The simulation was free to select vital rates from a very wide range of possibilities. However, the posterior distributions (Fig. 2) lay within the ranges expected from empirical observations. As illustrated for the North Sea (Fig. 2), and as might be expected, there was greatest uncertainty in the first year survival rate.

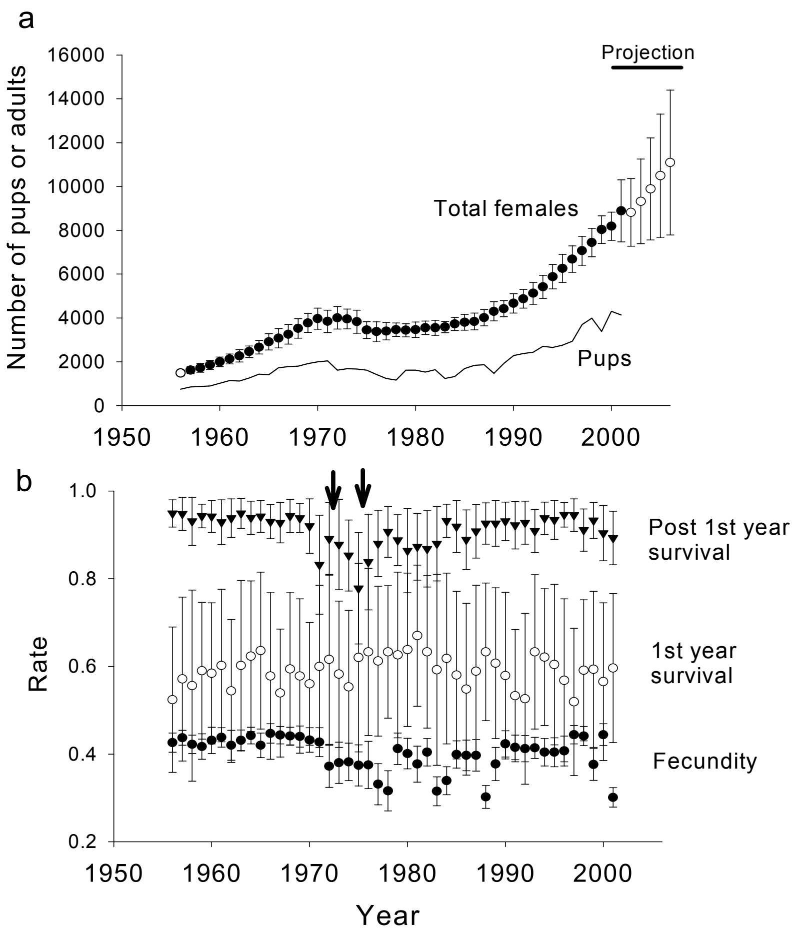

Figure 2. Changes in the number of pups and post-first year females in the North Sea section of the UK grey seal population (a). Panel b shows the variability and posterior distributions of vital rates through time for the same section of the population. Arrows show when the major culls took place at the Farne Islands in 1972 and 1975. See legend to figure 2 for a description of the projection.

Projection of the population

Since we know very little about how density dependence will operate there are no grounds for forward projection of the population other than to assume that the recent population history is indicative of future trends. Even if we were to assume that first year survival or fecundity were likely to be affected by population density to a greater extent than post-first year survival, we have no information about the carrying capacity for each of these vital rates.

In this case, population projection has been carried out by running the simulation forward for 5 years using bootstrapped values of the posterior distributions of vital rates for the previous 5 years. Confidence limits were calculated by repeating the process for 1000 sets of simulations. The results are shown in Figure 3.

Projection suggests that the populations in the Hebrides are most likely to stabilise over then next 5 years whereas those in Orkney and the North Sea will continue to increase. In addition, overall, the UK grey seal population is likely to continue to increase for the foreseeable future. However, the confidence intervals on these projections are very large. For example, by 2006, the number of female grey seals associated with regularly surveyed sites could lie between 63,000 and 123,000 individuals (Fig. 3). This compares with the current range of 65,000-86,000 for the same section of the population.

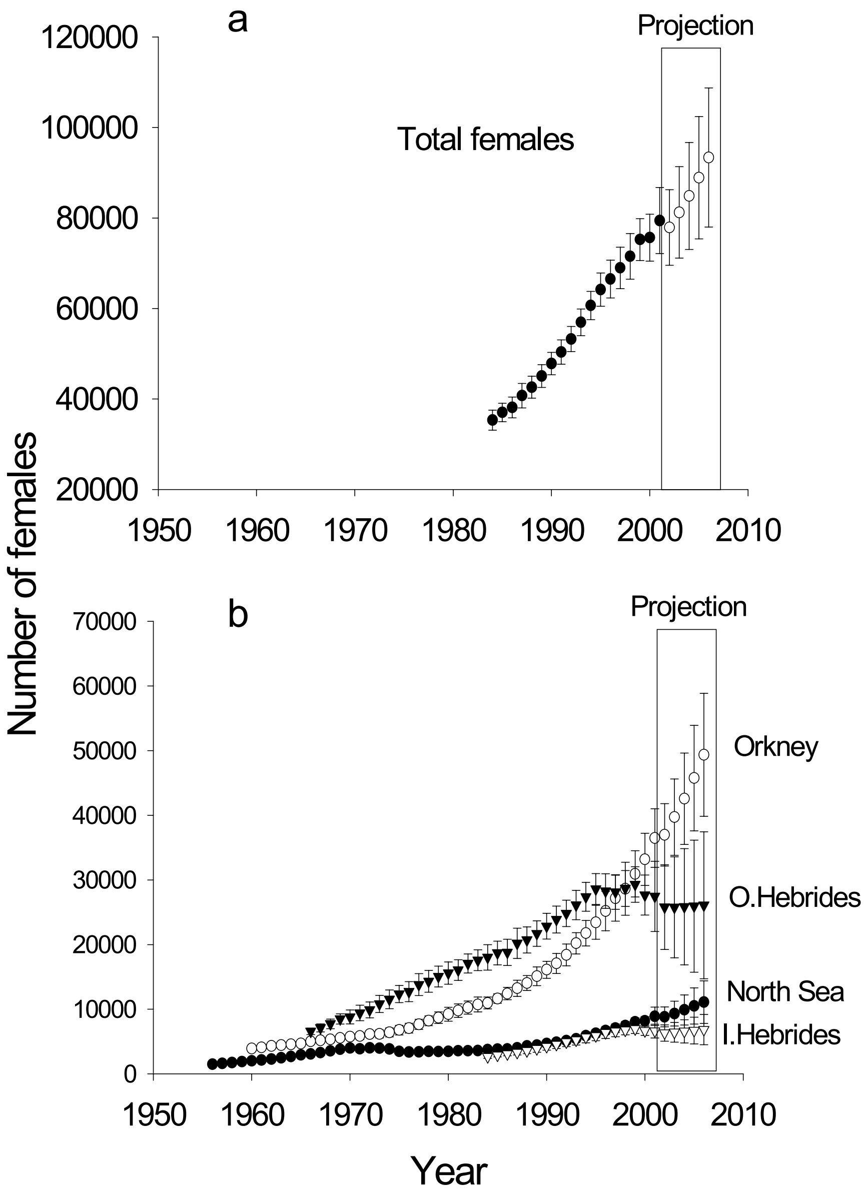

Figure 3. The total number of females (a) in the UK grey seal population and (b) in each region. The mean estimate is shown for each year in which there is an estimate of pup production and this is shown with the standard deviation. In addition, the result of population projections to 2006 are shown using the distribution of vital rates from each section of the population over the period 1997-2001. The projection for the total population is the sum of the projections for each region.

Estimating population size associated with sites surveyed infrequently

Pup counts are occasionally available from locations that are not part of the annual aerial surveys. In the order of 5,000 pups are born at these sites (SCOS 2002 ANNEX II). In order to estimate the total female population associated with these sites, a multiplier can be applied to the number of pups based upon the age structures calculated in the simulations of the population in the 4 main regions. The mean multipliers for the 4 regions were: North Sea, 2.05 (SD=0.24); Orkney, 2.05 (SD=0.19); Outer Hebrides, 2.27 (SD=0.11); Inner Hebrides, 2.01 (SD=0.23). Since the number of seals at many of the sites not surveyed frequently is not changing rapidly (e.g. in SW Britain), the multiplier for the Hebrides is likely to be the most appropriate. This suggests that there are 10,000-12,500 female seals associated with these additional sites.

Total population size

According to this analysis, the total female population size at regularly surveyed sites in 2001 was between 65,000 and 94,000 individuals. The historical total female population size and the numbers of female seals associated with each region are shown in Figure 3. Including sites surveyed less frequently puts the total female 1+ population at 75,000-106,500.

We cannot model the population of males in the same way as for females but on the assumption that the male population is about 60% of the female population the total population of grey seals associated with regularly surveyed sites is between 122,000 and 168,000 with a median of 144,000. The number of seals in the grey seal population together with the annual percentage change in the pup production and the total population are shown in Figure 4.

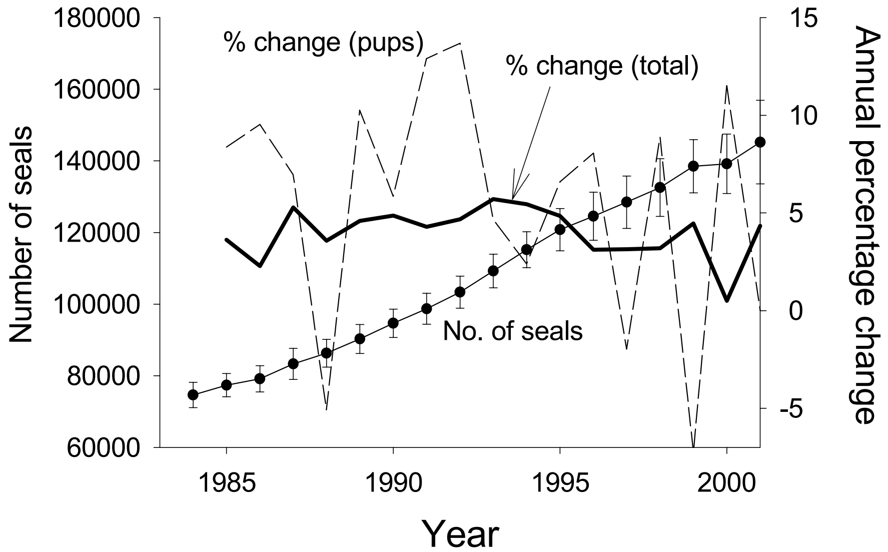

Figure 4. The estimated total number (±SD) of seals in the UK grey seal population and the annual percentage change in the population (solid line) and the pup production (dotted line).

Comparing the results of different methods of estimating total grey seal population size

The results from the methods of estimating total population size used by Hiby and Duck (in press) are shown in Table 1.

Table 1. Estimated size of the grey seal population associated with all major, annually monitored, breeding colonies in Scotland and eastern England, except Loch Eriboll, Helmsdale and Shetland. Estimates refer to the number of seals aged 1 and over at the start of the 2001 breeding season.

Year	Estimated pup production (survey)	Total female population Hiby & Duck	Total population Hiby & Duck
1984	14,992	25,824	44,489
1985	16,265	27,274	46,956
1986	17,796	28,983	49,923
1987	19,035	30,804	53,090
1988	18,071	32,674	56,332
1989	19,926	34,511	59,481
1990	21,093	36,363	62,622
1991	23,815	38,361	66,017
1992	27,075	40,570	69,795
1993	28,338	42,878	73,740
1994	29,018	45,349	77,982
1995	30,932	47,853	82,255
1996	33,426	50,561	86,895
1997	32,771	53,469	91,893
1998	35,680	56,497	97,082
1999	33,103	59,648	102,546
2000	36,915	62,905	108,027
2001	36,920	66,522	114,244

Table 2. Pup production and associated population size for the main, annually monitored grey seal breeding colonies in 2001.

Location	2001 pup production	Change in pup production from 2000	Total 2001 population (to nearest 100)
Inner Hebrides	2,938	-9%	9,100
Outer Hebrides	12,325	-8%	38,100
Orkney	17,523	+10%	54,200
Isle of May & Fast Castle	2,253	-10%	7,000
Farne Islands	1,247	+6%	3,900
Donna Nook	634	+3%	2,000
Subtotal	36,920	0%	114,200
SW England & Wales	1,500		4,600
All other colonies	3,500		10,800
Total	41,920		129,700

The estimate of the total grey seal population at annually monitored colonies was 114,000 in 2001. The 95% confidence limits for the entire female population are within 14% of the point estimate (57,000-75,000). The table above has been generated using the same method as in previous years. Figure 5 shows the population trajectories together with the predictions for the years 2002-2007. Table 2 shows the total population sizes associated with each section of the grey seal population based upon the Hiby & Duck model.

The results of the analyses from the new method described by Newman *et al*. together with those from the present analysis are described in Table 3. This shows that the point estimate for the population size was 107,000 using the Newman method and 127,000 using the current analysis. There is however, considerable overlap in the upper and lower and lower bounds. Overall, therefore, these three methods give estimates of total population size in the annually monitored portion of the population that are not significantly different from each other. Nevertheless, the greater level of statistical rigour in the models of Hiby & Duck and Newman *et al.* means that greater weight should probably be placed upon their estimates than that of the current illustration.

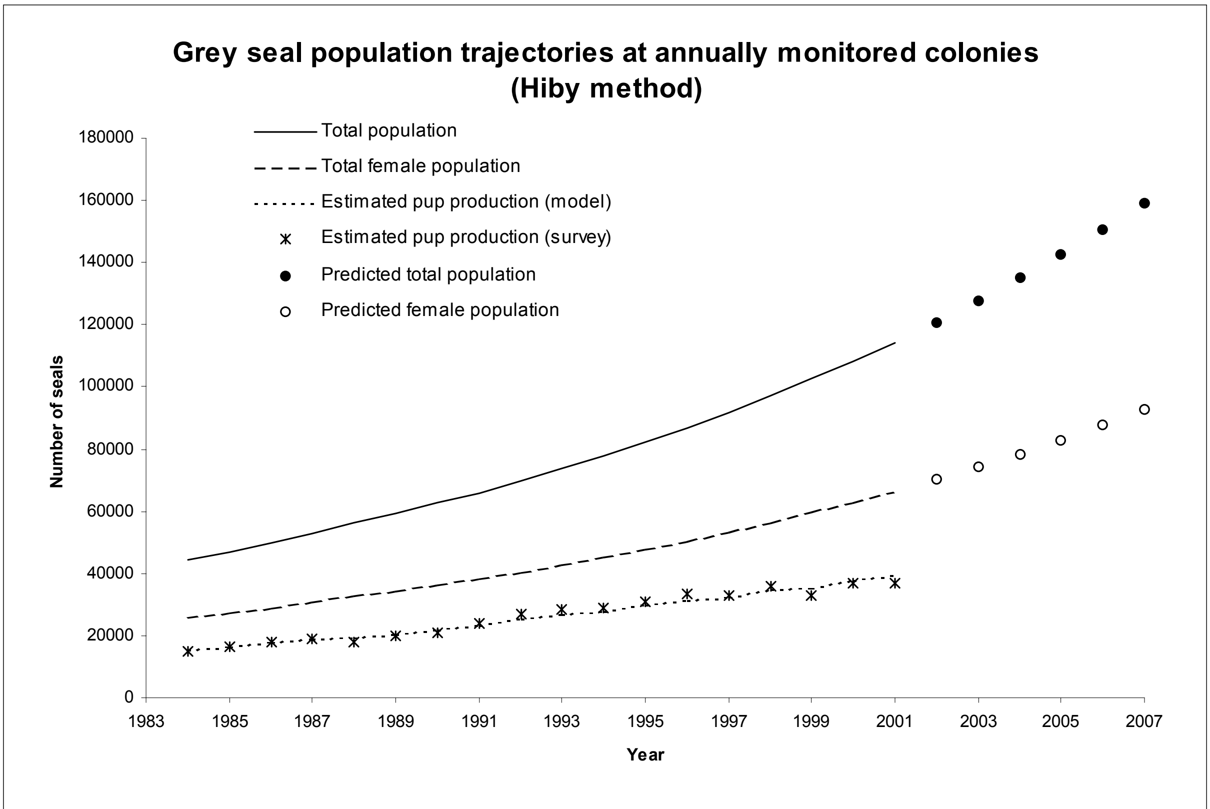

Figure 1. Grey seal population trajectories at the annually monitored colonies around Britain. These data have been generated using the Hiby & Duck method and can be compared with results presented to SCOS in previous years. Predictions for the years 2002 – 2007 are included.

Table 3. Comparison between estimates for 2001 from Newman *et al.* (SCOS 2002) and the simulation results for 2001 described here for the adult male plus female population size at annually surveyed sites.

	Newman *et al.*			Current analysis		
	Estimate	Lower	Upper	Estimate	Lower	Upper
North Sea	11,741	7,586	18,080	14,214	9,771	18,658
Orkney	58,498	31,767	84,819	58,360	44,113	72,604
O Hebrides	29,494	20,404	54,640	43,910	26,856	60,964
I Hebrides	7,138	5,320	12,422	10,582	7,273	13,890
Total	106,871	65,077	169,961	127,066	88,013	166,116

Future model development

Unlike the Hiby & Duck approach the Newman model includes density-dependence in at least one demographic variable and is being developed as a tool for modelling the dynamics of grey seal populations in the UK. Because of the way in which it has been written and also because of changes in personnel at

SMRU, the Hiby & Duck model can no longer be supported. The intention is, therefore, to move to an alternative model, such as the Newman model, as soon as possible.

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Information papers provided for SCOS

1. Newman, K., Thomas, L. & Harwood, J. (2002) Estimates of the current size of the different components of the British grey seal population based on a spatially-explicit state-space model.

2. Hall, A.J. (2002) Phocine Distemper Epidemic in European Harbour Seals, 2002. SCOS information paper.

3. Matthioloulos, J. Estimating spatial usage by marine mammals. SCOS information paper.

Estimates of the current size of the different components of the British grey seal population based on a spatially-explicit state-space model.

Ken Newman, Len Thomas and John Harwood

Introduction and Methods

We have developed a spatially-explicit model of the dynamics of the British grey seal population using an application of the state-space framework (Akoi 1990) developed by Buckland et al. (submitted) for population dynamic applications. One characteristic of the state-space approach is that the true, but unknown, state of the population is modelled by a state process which is linked to survey data by a separate observation model. The state process model incorporates stochasticity in demographic rates. Posterior distributions for parameter values and population sizes can be generated using numerical Bayesian approaches. In this case, we have used a Markov chain Monte Carlo algorithm. Our model departs from a strict state-space approach in that the state process is 6^{th} order, rather than 1^{st} order, Markovian. This reflects the fact that animals are not recruited to the breeding population until their 6^{th} birthday.

Our state process model includes functions for density-dependent juvenile survival and density-dependent migration. Although we believe that these processes probably operate at the level of individual colonies, we have not yet been able to implement a model at this spatial scale. Instead, we have aggregated colonies into "super-colonies" that are equivalent to the regional divisions traditionally used to summarise the results of SMRU's surveys: North Sea (Isle of May + Fast Castle + Farnes + Donna Nook), Inner Hebrides, Outer Hebrides, and Orkney. Juvenile survival and migration in a particular year are assumed to be related to the total number of pups in each super-colony. Adult survival (applied to all 1+ animals) and fecundity are assumed to be the same for all super-colonies. The number of adults surviving each year was assumed to be a binomial variable.

Juvenile survival (ϕ_{jct}) at super-colony *c* in year *t* is described by a Beverton-Holt function of the form:

$$\phi_{jct} = \frac{\alpha}{1 + \beta_c \mathbf{n}_{0c,t-1}}$$

where α is the maximum value for juvenile survival, and $1/\beta_c$ reflects the carrying capacity of all the colonies within super-colony *c*, following Harwood (1981) The number of pups surviving to the end of the first year was also assumed to be a binomial variable whose probability was determined by the above expression multiplied by adult fecundity and the number of 6+ animals (i.e. those six years and older).

We have assumed that only females recruiting to the breeding population for the first time will migrate, and that the probability of their moving from their natal super-colony to another super-colony is a function of the difference between juvenile survival at the two sites, and distance between super-colonies. Colony-specific multinomial distributions are assumed for movement from one super-colony to any other (including to itself, i.e., not moving), and the proportions are based upon the extension of the logit transform for a binomial proportion to multinomial proportions:

$$\log\left(\frac{p_{c\to b,t}}{p_{c\to c,t}}\right) = \gamma_1(E[\phi_{jb,t+1}] - E[\phi_{jc,t+1}]) + \gamma_2 d_{cb} + \gamma_3 I_{b=c}$$

where

$$E[\phi_{jb,t+1}] = \frac{\alpha}{1+\beta_b \psi n_{6+,c,t}},$$

d_{cb} is the average distance between all pairs of colonies within super-colonies *c* and *b*, and $I_{b=c}$ is an indicator for site *b* equalling site *c*.

In effect, this imposes a form of density-dependent fecundity, within a super-colony, on animals breeding for the first time. The only published evidence of density- dependent fecundity variation in phocid seals (Bowen et al 1981) involved animals in this age category.

We fitted this model to the "most consistent" time series of pup production estimates from 1984-2001, although the first six data points were used to establish the initial age structure of the population. We initially assumed that pup production estimates had a coefficient of variation (CV) of 5%, in line with the figure quoted by Duck et al. (submitted). However, this resulted in some very erratic population trajectories, particularly for the later years in the time series. We therefore repeated the fitting procedure using a CV of 10%.

Results

Figure 1 shows the median trajectory for 50,000 permutations drawn at random from the prior distributions and then filtered according to their contribution to the overall likelyhood. Figure 2 shows the posterior distributions for the demographic parameters.

Overall, the model provides a reasonable representation of the observed changes in pup production over the last decade. However, it cannot completely capture the very rapid levelling off of pup production in the Inner and Outer Hebrides in the mid-1990s, or the rapid increase in pup production observed in Orkney at about the same time. It may be possible to reconcile these inconsistencies if older females are also allowed to migrate.

Estimates of the total population of 1+ animals at the start of each breeding season in all the super-colonies combined are approximately 10% higher than those obtained using the method of Hiby et al (in press), which assumes that the population is increasing exponentially. Table 1 shows the median, and upper and lower 95th percentiles for the posterior distributions of population size in 2001. Following Hiby et al. (in press), we have assumed that there are equal numbers of male and female seals up to the age of 5 years and that beyond this age males suffer higher mortality, so that male numbers are 60% of females. The difference between our figures and those obtained using the method of Hiby et al. is primarily due to the lower estimates of fecundity (0.921 vs 0.954) and adult survival (0.94 vs 0.97) we have obtained. Juvenile survival in the Inner and Outer Hebrides must have fallen to a relatively low value (0.27 and 0.24 respectively) if it is to account for the observed slowing down of pup production. We estimate that juvenile survival in Orkney is 0.57, and 0.43 in the North Sea. This compares with Hiby et al.'s estimate of 0.39 for the entire British population. Hall et al. (2000) estimated that the survival of female grey seal pups in the North Sea from weaning to age one was 0.62. Survival from birth to weaning varies from colony to colony, but estimated values are centred around 0.8, suggesting an overall first year survival of 0.5.

We can use the posterior distributions for the demographic parameters and population sizes to obtain projections of the population's potential dynamics over the next five years. Figure 2 shows population trajectories until 2006 obtained by resampling from these distributions. We predict that the total size of populations associated with colonies in the Inner and Outer Hebrides will increase by less than 10% over this period, but population numbers in the North Sea and, particularly, Orkney will continue to increase by 5-7% annually. However, these are preliminary figures and there is substantial uncertainty associated with these projections.

Discussion

Clearly, further work is required before this model can provide an entirely convincing description of observed changes in pup production in the different super-colonies. We will try to address the following issues over the next year:

- improvement of the model of migration to take account of additional data from mark-recapture, genetic and telemetry studies (this will be carried out by a PhD student funded under the NERC/EPSRC Environmental Mathematics and Statistics programme);
- obtaining more realistic values for the uncertainty associated with estimates of pup production;
- developing a methodology for obtaining colony-specific estimates of pre-weaning pup survival from aerial photographs;
- investigating of alternative forms of density-dependence in survival and fecundity;
- incorporating environmental stochasticity in adult survival and/or fecundity;
- developing an equivalent model at the scale of individual colonies.

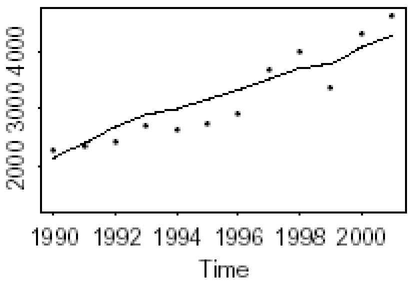
In addition, we will consider what needs to be done to obtain reliable estimates of the male component of the population.

Table 1. Projections of the size of the various components of the British grey seal population at the start of the 2002 and 2006 breeding seasons. The 2.5th and 97.5th percentiles can be treated as the equivalent of upper and lower 95% confidence limits.

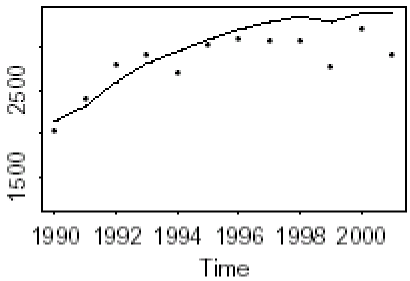
	2.5th percentile	***Median***	97.5th percentile	2.5th percentile	Median	97.5th percentile
"Super-colony"	2002			2006		
North Sea	11,844	**16,520**	21,636	11,521	**20,498**	31,620
Inner Hebrides	7,578	**10,243**	14,399	6,810	**11,148**	18,298
Outer Hebrides	27,410	**37,719**	52,615	23,216	**40,724**	65,694
Orkney	53,286	**75,102**	95,556	56,696	**99,234**	151,637
Total	100,118	**139,584**	184,206	98,243	**171,604**	267,249

Figure 1. Predicted and observed trajectories for grey seal pup production at four British "super-colonies". A. North Sea, B. Inner Hebrides, C. Outer Hebrides, D. Orkney

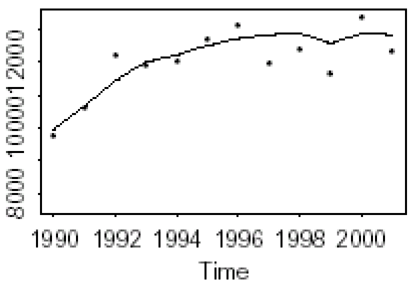
A. North Sea



B. Inner Hebrides



C. Outer Hebrides



D. Orkney

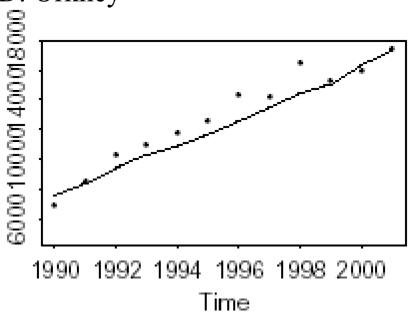


Figure 2. Prior and posterior distributions for demographic parameters.

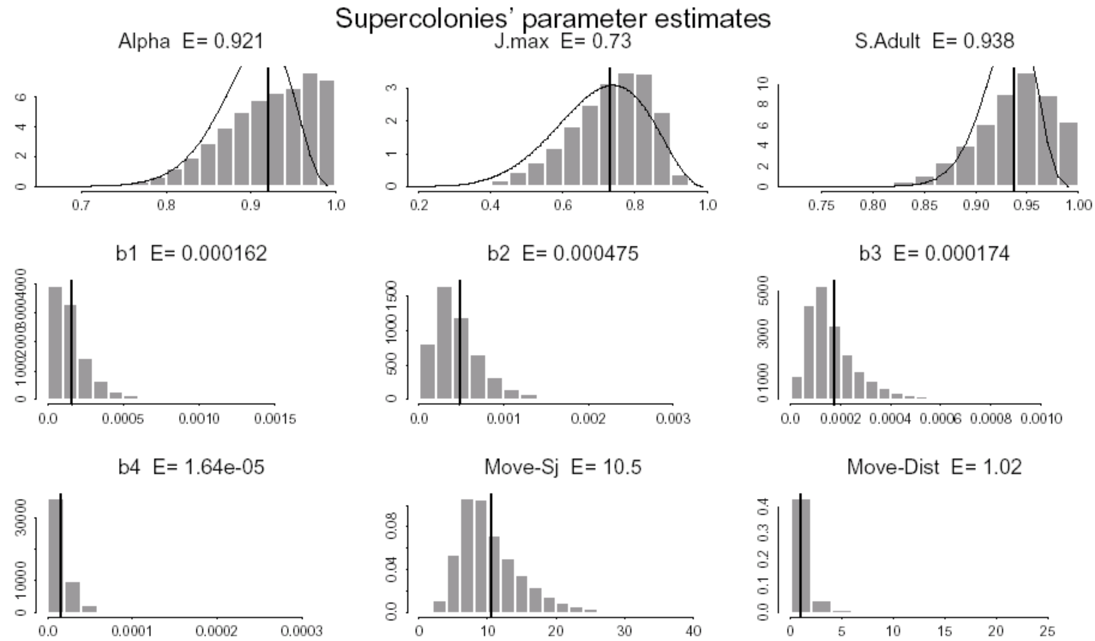
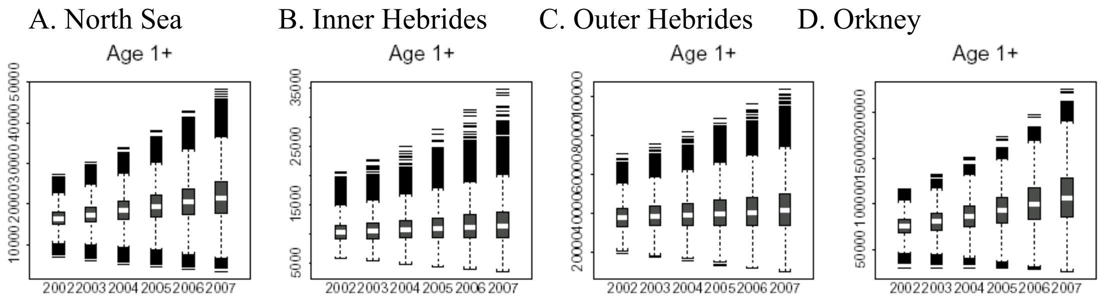


Figure 3. Population projections for four British grey seal "super-colonies". A. North Sea, B. Inner Hebrides, C. Outer Hebrides, D. Orkney.



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Phocine Distemper Epidemic in European Harbour Seals, 2002

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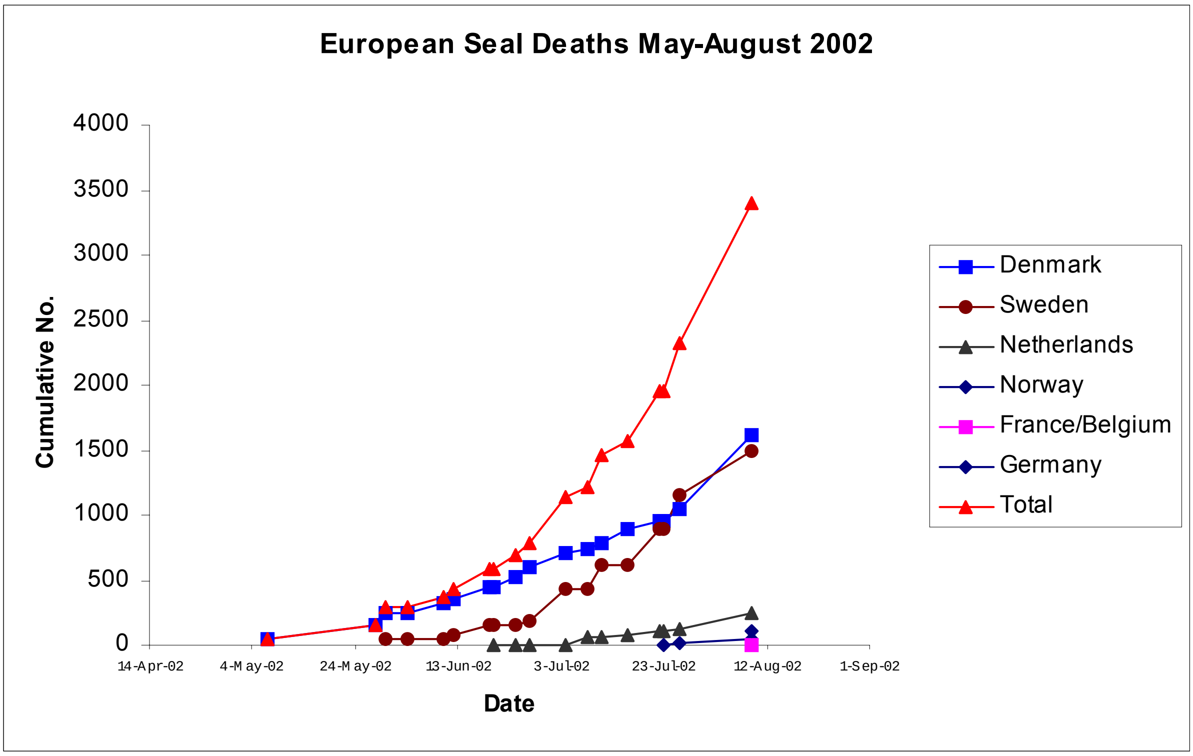
In May 2002 an unusually high mortality among harbour seals, *Phoca vitulina* breeding on the Danish island of Anholt in the Kattegat was reported. Some carcasses were recovered and post-mortem examinations confirmed the cause of death to be phocine distemper virus (PDV). Virological investigations determined there was a 97% identity between this virus and the 1988 PDV strain[1]. Since then the disease has spread from seals in the Danish and Swedish Kattegat and Skagerrak into the population inhabiting the Dutch and German Wadden Sea. Almost 3,500 dead seals have now been counted with the number still rising (Fig 1.). To date one case has been confirmed in a seal found on the Northern French coast near the Belgian border and three possible cases in the UK are being investigated at present.

A dedicated telephone line for reporting dead and sick seals has been set up at the Institute of Zoology in London, who will be coordinating the UK investigation. Scottish Agricultural College VIC in Inverness will carry out all post mortems on Scottish seals. SMRU will assist with disseminating information via an e-mail list to all interested governmental, NGO and scientific parties, will keep a dedicated web page updated weekly and ensure necessary data are collected for subsequent epidemiological modelling. Some post mortem, serology and virology may be undertaken if necessary.

[1]Jensen, T., van de Bildt, M., Dietz, H.H., Andersøn T.H., Hammer, A.S., Kuiken, T. and Osterhaus, A. (2002). Another phocine distemper outbreak in Europe. Science, 297, 209.

Fig. 1



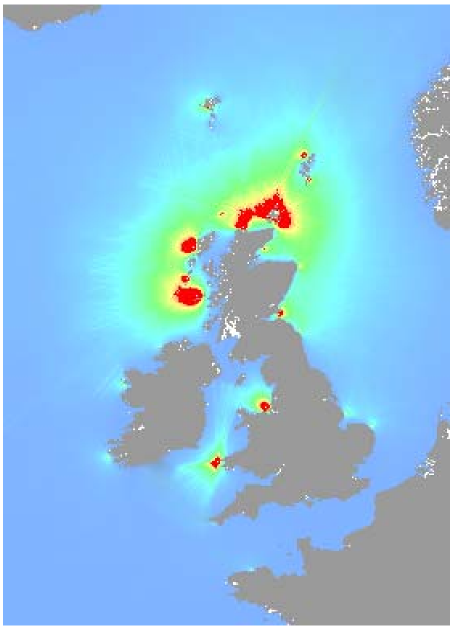
Estimating spatial usage by marine mammals

J. Matthiopoulos, SMRU

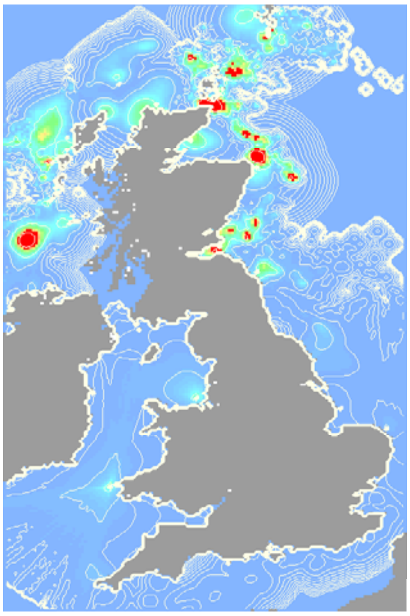
Over the last five years SMRU has been developing expertise, in modelling animal movement, specifically in relation to marine mammals.

As a result, a considerable amount of mathematical and numerical techniques have now been developed and organised into software libraries for ease of implementation and modification.

Specific applications currently include estimating the range of the population of British grey seals and North American steller sea lions.



Modelling the range of the British grey seal population.



Estimating spatial usage by the British grey seal population

Models of movement are closely interlinked with techniques of statistical estimation through the concept of model-supervised usage estimation developed within SMRU.

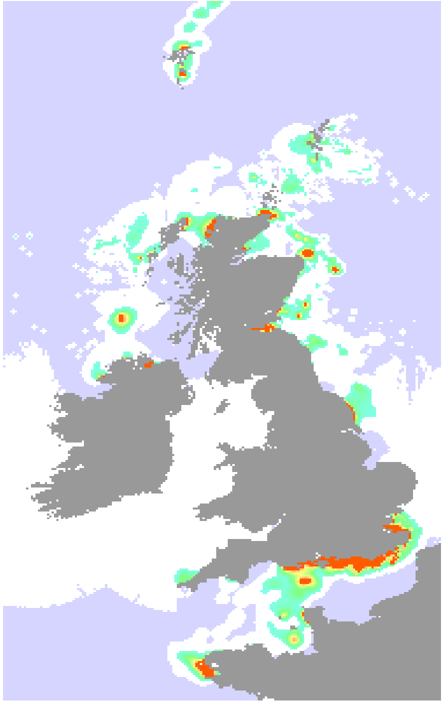
We use auxiliary information and mechanistic modelling to assist the estimation of spatial usage from sparse telemetry data.

These estimates are considerably more accurate than those obtained via traditional methods such as kernel smoothing.

Discrepancies between the models' predictions and the final estimate of spatial usage can be very informative.

In fact, these discrepancies can serve as the first step in a quantitative investigation of habitat preference by identifying which environmental attributes might be considered as covariates of usage.

Of course, a trained observer could identify such hotspots by looking at the raw data from a group of tagged animals. But how easy would it be to make quantitative statements about the entire population of animals just by eyeballing the data?



Hotspots of spatial usage in British grey seals. Light purple indicates that the animals used those parts of space less than originally expected. The gradient from green to red is used to show usage that exceeds prior expectations.