BASELINE SEAL INFORMATION FOR THE FTOWDG AREA

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INTRODUCTION

BACKGROUND

The Forth and Tay Offshore Wind Developers Group (FTOWDG) consists of three individual developers, each granted exclusive development rights by The Crown Estate for an area of the outer Firth of Forth and Tay. These sites are shown in Figure 1.

The aim of this report is to present an analysis of existing satellite telemetry and aerial survey data to describe the abundance and distribution of harbour (or common) and grey seals in the Firths of Forth and Tay, specifically to inform site specific and cumulative assessments of the likely nature and extent of potential impacts from the development of offshore wind farms in the region.

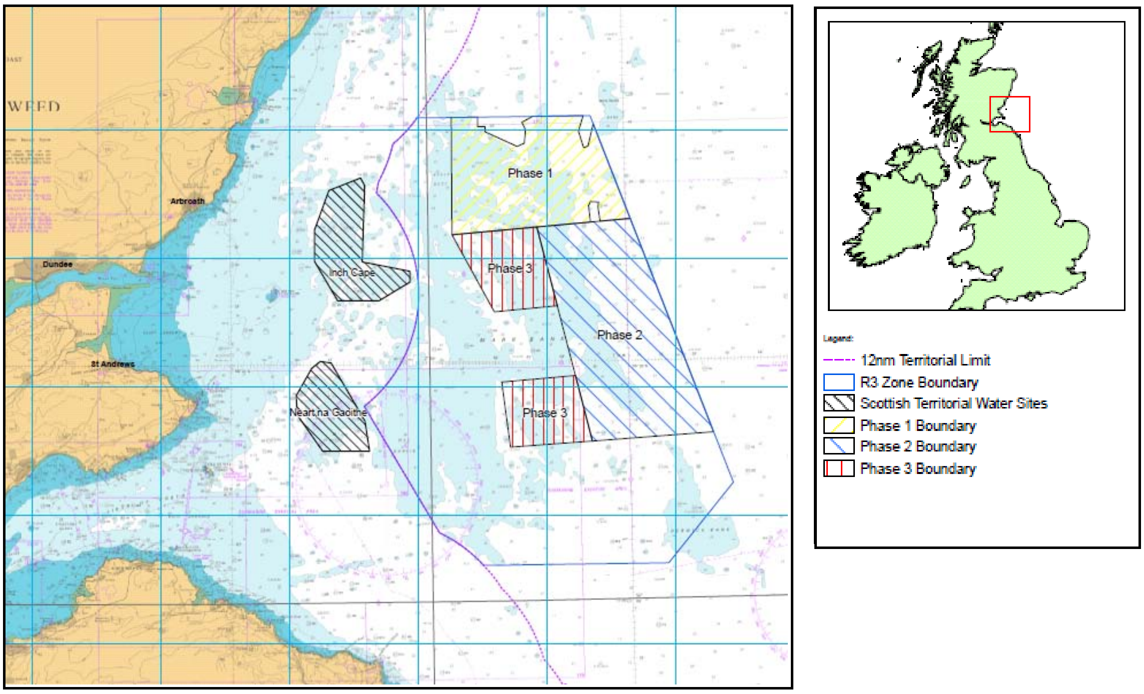


Figure 1. Map of FTOWDG development sites.

LEGISLATION PROTECTING SEALS

In Scotland seals are protected under the Marine (Scotland) Act 2010. Section 6 of this Act prohibits the taking of seals except under licence. Licences can be granted for the protection of fisheries and aquaculture and for scientific and welfare reasons. The Natural Environment Research Council (NERC), through the Special Committee on Seals (SCOS) and the NERC sponsored Sea Mammal Research Unit (SMRU), provides advice on all licence applications and haul out designations.

Both grey and harbour seals are listed in Annex II of the EU Habitats Directive, requiring specific areas to be designated for their protection. To date 16 Special Areas of Conservation (SACs) have been designated specifically for seals. Seals are features of qualifying interest in seven additional SACs.

The SACs with seals as qualifying interests relevant to an assessment of the likely impacts of wind farm developments in the FTOWDG region include: the Firth of Tay and Eden Estuary (harbour seals), Isle of May (grey seals), Berwickshire and North Northumberland Coast (grey seals), Dornoch Firth and Morrich More (in the Moray Firth; harbour seals) and Faray and Holm of Faray (in Orkney; grey seals).

The Marine (Scotland) Act 2010 introduced Seal Conservation Areas (replacing Seal Conservation Orders or COs). This was in response to local declines in harbour seal numbers and the aim was to provide additional protection for vulnerable local populations. Ministers must not grant a licence unless they are satisfied that there is no satisfactory alternative and that the granting of a licence will not be detrimental to the maintenance of the harbour seal population at favourable conservation status. The two existing COs which were introduced under the Conservation of Seals Act 1970 (the Conservation of Seals (Scotland) Order 2004 which protects both species year-round in the wider Moray Firth from Wick to Fraserburgh, and the Conservation of Seals (Scotland) Order 2007 which protects seals in the Northern Isles and the Firths of Forth and Tay) continue in the form of Seal Conservation Areas. Additional provision was made for a Seal Conservation Area for harbour seals in the Western Isles. Seven 'Seal Management Areas' have been defined by Marine Scotland based on advice from SMRU (SCOS 2010). These are East coast, Moray Firth, Orkney and North coast, Shetland, Western Isles, West Scotland and South-West Scotland.

The Marine (Scotland) Act 2010 also introduced provision for the protection of seals at a number of designated haul out sites around the Scottish coasts. This is designed to protect seals from harassment at these sites. There is one proposed haul out site relevant to FTOWDG - Kinghorn Rocks in the Firth of Forth.

POTENTIAL IMPACTS

The key potential impacts on seals identified by FTOWDG are:

- Disturbance or physiological effects as a result of underwater noise arising from construction, operational and maintenance activities associated with the wind farm development(s)
- Potential longer term avoidance of the development area
- Increased collision risk due to construction and maintenance traffic
- Potential reduction of the feeding resource due to the effects of noise, vibration, and habitat disturbance on important prey species

RESEARCH QUESTIONS:

A number of research questions have been defined which are relevant to determining the nature and extent of any impacts:

1. What is the predicted density of seals over the predicted 'impact footprint'? This 'impact footprint' will vary for each defined impact e.g. the impact for construction noise will likely extend beyond individual site boundaries. This will allow a quantification of the number of seals of each species potentially at risk for each identified impact. If possible these estimates should be temporally explicit to allow

assessment of how an impact may vary seasonally and between years. Uncertainty in predictions should also be provided.

2. What are the total sizes of the relevant seal populations? This is necessary to put predictions from 1. into context and allow the significance of any impacts to be assessed.
3. Where seal distribution and impact footprint overlap, what are seals using these areas for (e.g. foraging or transit)? How can we quantify this in such a way as to help assess the nature and significance of any impact and assess the implications of displacement from these areas? How many seals are regularly transiting through or foraging in defined 'impact zones'? Are there alternative areas available to seals if they were displaced from the areas they currently use? What would the implications be if seals were displaced to alternative foraging sites or had to shift their transit routes?
4. What is the level of connectivity between SACs and seals using the area?
5. Is there any potential for disturbance/impacts at breeding/haul out sites?
6. What is the diet of the two species of seals in the area? This, along with information provided by the assessment of any impacts on fish species, will be important in assessing the likelihood and magnitude of indirect impacts on seals due to the effects of wind farm development on important prey species.

The ability to answer these questions depends on an understanding of the distribution and abundance of seals in the area likely to be affected by activities associated with the construction and operation of the wind farms. This report presents details of the data available and analyses carried out to characterise the baseline conditions of seal abundance and distribution. There are three main sections of data presentation; the first details population counts in the region, the second seal tracking data and derived metrics, and the third section describes what is known about seal diet in the area (to allow an assessment of potential indirect impacts mediated through effects on prey species). This report contains no detailed consideration of impacts as this is outside the scope of the baseline description. A second report which details the findings of the noise impact assessment work being carried out using the seal density surfaces presented here will be provided subsequent to this report.

SEAL POPULATIONS

Unlike cetaceans, seals spend a portion of their time on land and are therefore easily observable for counting. SMRU carries out surveys of harbour and grey seals in Scotland and on the east coast of England to contribute to NERC's statutory obligation under the Conservation of Seals Act 1970 '…to provide the (UK government) with scientific advice on matters related to the management of seal populations'. These SMRU surveys, as well as surveys by a number of other organisations (including Scottish Natural Heritage, Natural England, the Countryside Council for Wales, the National Trust and the Lincolnshire Wildlife Trust) form the routine monitoring of seal populations around the UK. The annually submitted 'SCOS Advice', which includes information on recent changes in grey and harbour seal numbers, can be found in the Special Committee on Seals (SCOS) reports on SMRU's website (http://www.smru.st-andrews.ac.uk/pageset.aspx?psr=411).

Seals are widely distributed around the UK coast and most surveys are carried out from the air by either light aircraft or helicopter. SMRU does not survey the entire UK coast; surveys are concentrated in Scotland and on the east coast of England (Lincolnshire and Norfolk) where seals are relatively abundant and easy to survey. All surveys are of seals that are hauled out on shore.

On account of differences in the breeding behaviour of harbour and grey seals, the two species are surveyed at different times in their annual cycle. Harbour seals tend to be dispersed when breeding and aggregate, to an extent, when moulting so the main harbour seal surveys are carried out during their annual moult in August, when the most reliable and consistent numbers of animals are hauled out. In contrast, grey seals aggregate at traditional colonies when breeding and grey seal surveys are designed to estimate the numbers of pups born at these colonies, between mid-September and the end of December. Harbour seals are also surveyed in a few areas during their breeding season in June and July. While grey seals are counted on all harbour seal surveys, harbour seals are very rarely seen on any of the grey seal breeding colony surveys.

It should be noted that a phocine distemper virus (PDV) outbreak occurred in 2002 (Härkönen et al. 2006).

SURVEY METHODS

HARBOUR SEALS

Surveys of harbour seals are carried out during the summer months. Breeding seals are surveyed in June and July. The main population surveys are carried out when harbour seals are moulting, during the first three weeks of August. The highest and most consistent numbers of harbour seals are believed to haul out ashore during their annual moult. To maximise the numbers of seals on shore and to reduce the effects of environmental variables, surveys are restricted to within two hours either side of afternoon low tides on days with no rain.

Areas differ in the frequency with which they are surveyed. In general, annual moult surveys are carried out in Lincolnshire and Norfolk (England), the Moray Firth and the Firth of Tay (Scotland). The remainder of the Scottish coast is surveyed approximately every four to five years, although there is considerable variation between areas.

Breeding season surveys are carried out annually in the Moray Firth and, in recent years, in Lincolnshire and Norfolk. A very limited number of breeding season surveys have been carried out on behalf of Scottish Natural Heritage in areas designated as SACs for harbour seals.

Harbour seals inhabiting rocky shores are surveyed using a helicopter equipped with a thermal imaging camera that can detect seals hauled out ashore at a distance of up to 3km. It is possible to differentiate between the two species using their thermal profiles, the group structure on shore, a 'real' image from a camcorder, directly using binoculars or retrospectively from high resolution digital photographs. In some instances, however, species identity is still uncertain and the seals are classified as 'species unknown'. Seals on sandbanks in the east coast estuaries are usually surveyed from a light aircraft using conventional, oblique photography.

The counts obtained represent the number of harbour seals that were on shore at the time of the survey and are an estimate of the minimum size of the population. They do not represent the total size of the local population since a number of seals would have been at sea at the time of the survey. Note that these data refer to the numbers of seals found within the surveyed areas only at the time of the survey; numbers and distribution are likely to differ at other times of the year.

GREY SEALS

Grey seals aggregate in the autumn to breed at traditional colonies. Their distribution during the breeding season is very different to their distribution at other times of the year.

SMRU's main surveys of grey seals are designed to estimate the numbers of pups born at the main breeding colonies around Scotland. Breeding grey seals are surveyed annually between mid-September and late November using large-format vertical photography from a fixed-wing aircraft. Over 60 colonies are surveyed annually between three and seven times, at 10 to 12 day intervals, through the breeding season. Total pup production for each colony is derived from the series of counts obtained. Approximately 40 additional colonies are surveyed less regularly. The main grey seal breeding colonies in Shetland, England, Wales and Northern Ireland are counted by other, local, organisations.

Grey seals are also counted during SMRU's harbour seal surveys in the summer. However, counts of grey seals during the summer months can be highly variable and although these counts are not used as a population index, they provide useful information on the summer distribution of grey seals.

In addition to these standard surveys, as part of a BERR (now DECC) funded project, a series of monthly grey seal counts were undertaken between April and September 2008 at haul out sites on the east coast of Scotland and north east coast of England using a fixed wing aircraft.

These surveys extended from the Rattray Head area south to Coquet Island (30km south of the Farnes).

SUMMARY

1. Population surveys of harbour seals are carried out during their annual moult in August.
2. Harbour seal moult surveys provide an estimate of the minimum size of the population, *not* the total population size.
3. Harbour seal breeding season surveys are carried out annually in east England and the Moray Firth, and infrequently elsewhere.
4. In general, harbour seal population (moult) surveys are carried out once every four to five years in most of Scotland but annually in Lincolnshire, Norfolk, the Moray Firth and the Firth of Tay. The frequency of surveys is determined by availability of funds.
5. Grey seals are also counted during harbour seal surveys. Their numbers are highly variable in the summer months.
6. A series of monthly counts of grey seals at haul outs along the east coast of Scotland and north-east coast of England was carried out in Summer 2008.
7. The main grey seal surveys estimate the number of pups born at the main breeding colonies around Scotland. The size of the grey seal population is then estimated using two different models (pup survival and fecundity).
8. Other organisations monitor the number of grey seal pups born in England, Wales, Northern Ireland and Shetland.
9. Results of all surveys are presented annually to the UK Government as part of NERC's statutory obligation under the Conservation of Seals Act 1970. These results are available in the SCOS documents on SMRU's website (http://www.smru.st-andrews.ac.uk/pageset.aspx?psr=411).

SEAL COUNTS

HARBOUR SEALS

POPULATION MONITORING/MOULT SURVEY COUNTS (AUGUST)

Harbour seals in this area have been counted in two ways at this time of year. The entire coast is surveyed approximately every four to five years using a helicopter equipped with a thermal imaging camera. Table 1 shows the number of seals counted in the Scottish Seal Management Areas to provide regional and national context for Forth and Tay counts. In addition, annual moult surveys are carried out in the Firth of Tay and Eden Estuary SAC from a light aircraft using conventional, oblique photography (Table 2 and Figure 2).

Most of the harbour seals in south east Scotland (south of Montrose) haul out along the Angus, Fife and Lothian coasts. However, numbers within these regions represent a small portion (~2%) of the total Scottish population (Table 1). In the 1990s, within the Forth and Tay region, the greatest numbers of seals were generally counted around the Fife coast – concentrated around the mouth of the Tay and the Eden Estuary, with lower counts in the Forth Estuary, the upper Tay and along the Angus coastline (Table 2). However counts in this area have declined dramatically since the early 2000s (Table 3 and Figure 3). Although only based on a single count (in 2010), there may be evidence that this decline is stabilising in the Eden and Tay area. The decline seen in the Tay and Eden Estuaries is similar to declines seen in other parts of the species' range, particularly in the Northern Isles. In other parts of the range, particularly the West of Scotland, harbour seal numbers are stable. In contrast to Scotland, numbers in south east England have increased dramatically, with counts in The Wash and North Norfolk population increasing 20% between 2008 and 2009 (SCOS 2010). The cause of these local declines is not yet known. A number of factors have been proposed as the cause of the decline: disease, killer whale predation, competition with grey seals, declines in important prey species and anthropogenic mortality. Investigations into some of these are continuing (SCOS 2010) but it is likely that the declines are multifactorial and that the factors responsible might be different in different areas.

The numbers presented represent minimum population estimates, since a proportion of the population will always be at sea when aerial counts are made. A study by Lonergan et al. (2011 – in SCOS 2011 in press) demonstrated that flipper tagged harbour seals hauled out on average 72% of their time during the annual moult (95% confidence interval 54-88%). Scaling up the most recent count of the East coast harbour seal population (Table 1) of 376 seals gives a local population estimate of 522 (427-696) seals. Scaling up the most recent count of the Firth of Tay and Eden Estuary SAC of 124 (Table 3) gives an SAC estimate of 172 (141-230).

Table 1. Minimum estimates of the UK harbour seal population from the most recent surveys in each area.

Seal Management Area	Current Estimate (2007-2009)	% of total for Scotland
Shetland	3003	15%
Orkney	2874	14%
Highland North Coast	112	1%
Outer Hebrides	1804	9%
West Scotland, Highland (Cape Wrath to Ardnamurchan)	4969	24%
West Scotland, Strathclyde (Ardnamurchan to Mull of Kintyre)	5834	28%
South West Scotland, Firth of Clyde (Mull of Kintyre to Loch Ryan)	811	4%
South West Scotland, Dumfries & Galloway (Loch Ryan to the English Border)	23	0%
East Scotland, Firth of Forth (Border to Fife Ness)	**148**	**1%**
East Scotland, Firth of Forth (Fife Ness to Fraserburgh)	**228**	**1%**
East Scotland, Moray Firth (Fraserburgh to Duncansby Head)	871	4%
TOTAL SCOTLAND	**20,677**	
TOTAL UK	**24,404**	

Table 2. The number of harbour seals counted on the south-east coast of Scotland during the most recent, and two previous, surveys carried out by helicopter equipped with a thermal imaging camera.

Region	1997	2005	2007
Tayside (Montrose to Newburgh)	92	101	166
Fife (Newburgh to Kincardine Bridge)	617	445	215
Central (Upper Forth)	0	0	1
Lothian (Kincardine Bridge to Torness Power Station)	40	104	55
Borders (Torness Power Station to Berwick upon Tweed)	0	0	0
Total	**749**	**650**	**437**

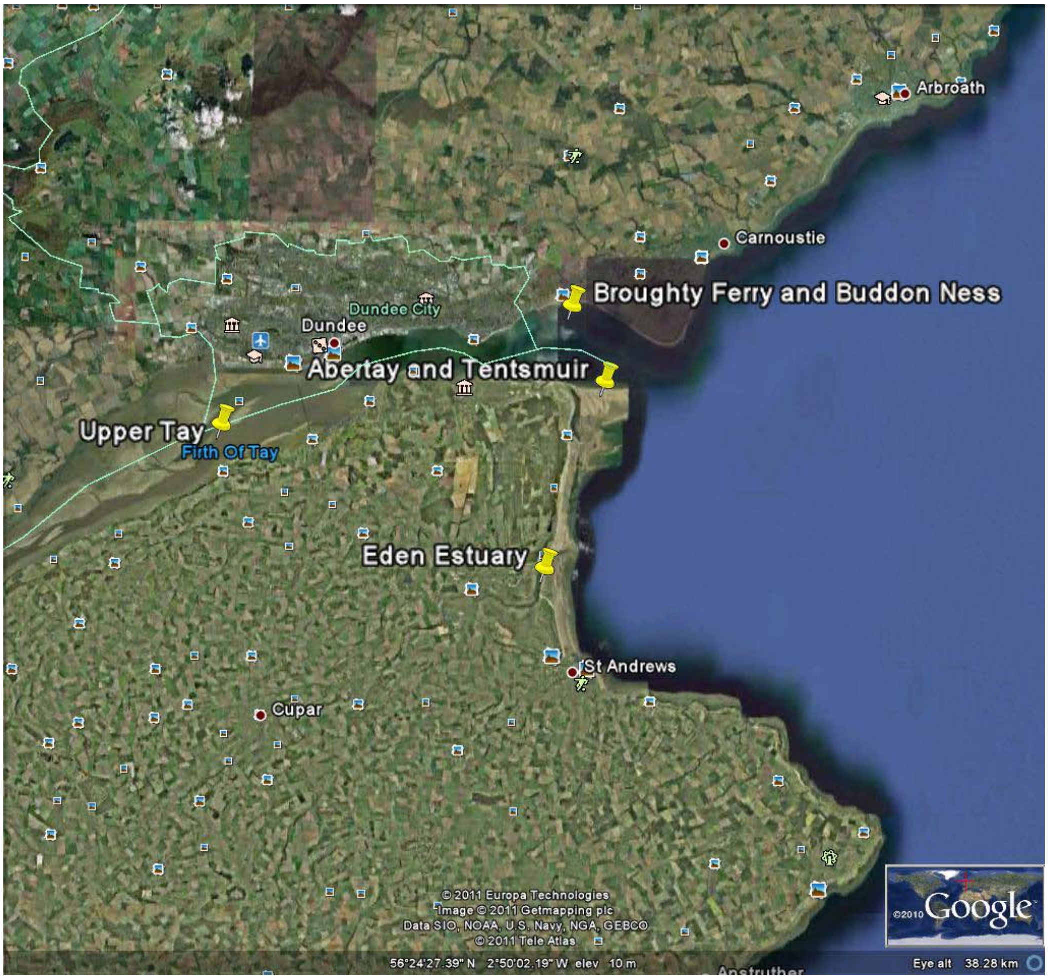


Figure 2 Google earth map showing the locations of seal haul outs within the Eden and Tay Estuary SAC.

Table 3. The number of harbour seals counted in the Firth of Tay and Eden Estuary SAC during surveys carried out over the last decade by light aircraft using vertical or conventional, oblique photography. Single counts were made in each year apart from 2005, when two counts were made and for which the mean has been presented.

Site	2000	2002	2003	2004	2005	2006	2007	2008	2009	2010
Eden Estuary	267	341	93	78	88	90	99	83	22	36
Abertay and Tentsmuir point	153	167	53	126	53	34	32	50	8	9
Upper Tay	115	51	83	134	85	91	62	49	45	41
Broughty Ferry and Buddon Ness	165	109	232	121	97	127	68	40	36	38
Firth of Tay and Eden Estuary SAC total	700	668	461	459	323	342	261	222	111	124

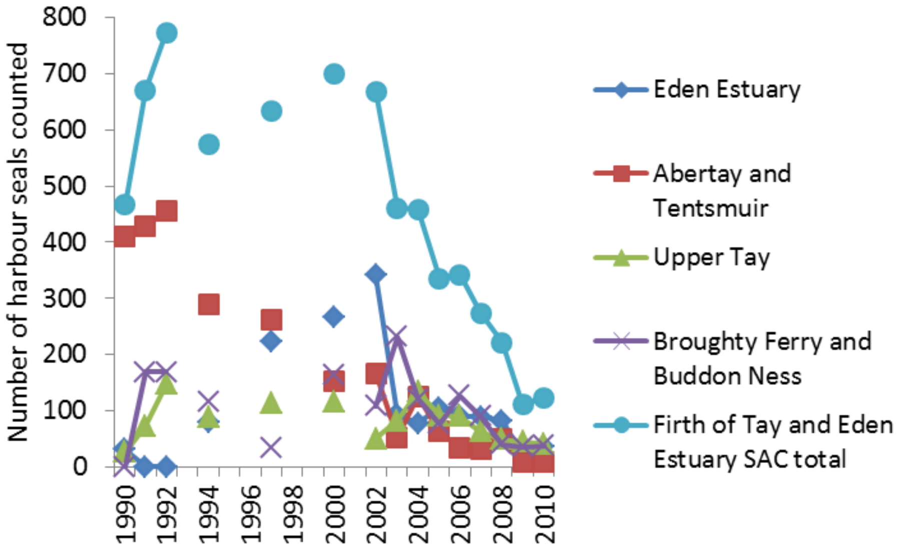


Figure 3. Trends in the number of harbour seals counted in the Firth of Tay and Eden Estuary SAC in the last two decades (Figure plotted using the same data that are presented in Table 2 and Table 3 with the addition of data from 1990-1994). The lines fitted to the data collected in consecutive years are presented in order to help identify patterns.

GREY SEALS

PUP PRODUCTION ESTIMATES (SEPTEMBER TO DECEMBER)

Most of the grey seals in the region breed at three locations (Figure 4): the Isle of May, an uninhabited island in the Firth of Forth; Fast Castle, a rocky beach on the Berwickshire coast; and at the Farnes Islands, a group of uninhabited rocky islands off the Northumberland coast. In total these sites represent 12% of the UK population. Seals breeding at the Isle of May and Fast Castle represent 10% of the total Scottish population. Pup production has been increasing at these colonies over recent years, particularly at Fast Castle and the Firth of Forth Islands (Table 6; Figure 5). Pup production at the Isle of May and Fast Castle increased by 21% between 2008 and 2009, mainly driven by the rapid increase in numbers at Fast Castle. The continuing increase of the North Sea grey seal population is in contrast to the majority of the UK grey seal populations (Orkney and the Outer Hebrides) where growth has levelled off after steady increases since the 1960s when records began.

Table 4. National grey seal pup production. N.B. The North Coast (Loch Eriboll and Eilean nan Ron) pup production estimate is for 2008 - the North coast was not surveyed in 2009.

Location	2009 pup production estimate	% of total for Scotland
Outer Hebrides	12113	29%
Inner Hebrides	3396	8%
North Coast	557	1%
Orkney	19150	47%
Shetland	831	2%
Moray Firth	1043	3%
Firth of Forth	**4047**	**10%**
TOTAL SCOTLAND	**41137**	
Farnes	1350	
TOTAL UK	**46782**	

Figure 4. Google Earth map showing the location of grey seal breeding colonies on the north-east coast of England and south-east coast of Scotland at which pup production has been estimated.

Table 5. Grey seal pup production estimates for breeding colonies on the north-east coast of England and south-east coast of Scotland for the last decade. Data are derived from aerial (photo) and ground counts carried out during the grey seal breeding season (September to December) by SMRU (Isle of May, Fast Castle, Firth of Forth islands), the Forth Seabird Group (Firth of Forth islands) and the National Trust (Farne Islands).

Colony	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Isle of May	1766	2133	1932	1977	1882	1953	1954	1827	1751	1875	2065
Fast Castle	268	381	321	532	717	659	764	804	1005	1265	1715
Firth of Forth islands					86	72	110	171	206	247	267
Farne Islands	843	1171	1247	1200	1266	1133	1138	1254	1164	1318	1346
Total	2877	3685	3500	3709	3951	3817	3966	4056	4126	4705	5393

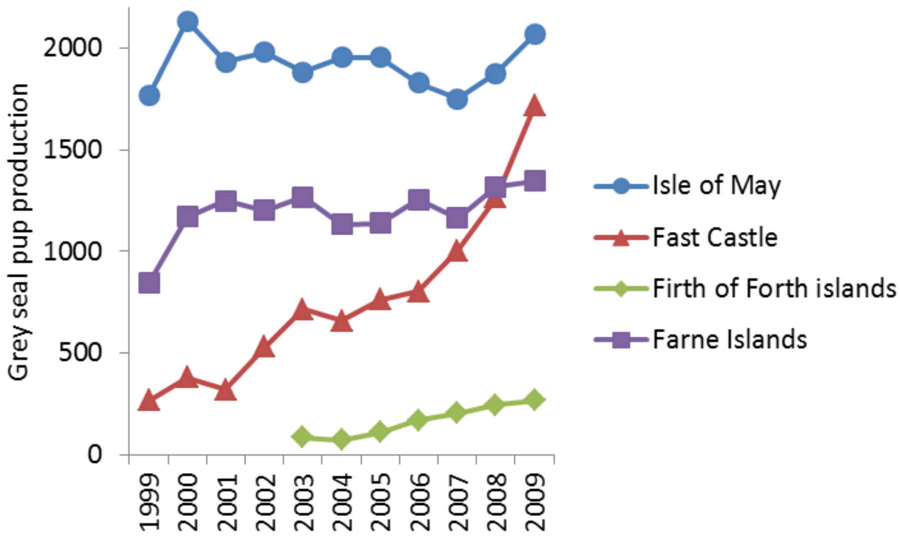


Figure 5.Trends in grey seal pup production at breeding colonies on the north-east coast of England and south-east coast of Scotland for the last decade (Figure plotted using the same data that are presented in Table 6). The lines fitted to the data are presented simply to help identify patterns.

GREY SEALS COUNTED DURING AUGUST

The distribution of grey seals counted around the coast during the August harbour seal moult surveys is similar to the patterns of distribution of breeding seals, with the largest concentrations being in the Western Isles and Orkney (Table 6). The proportion of seals counted on the East coast south of the Moray Firth (12%) was similar to that for pup production. Most of the grey seals in the East coast were counted around the Fife coastline (Table 8).

Table 6. The number of grey seals counted at haul outs around the coast of Scotland during recent harbour seal population moult counts in August.

Row Labels	Seal Management Area	Year surveyed	Count	% of total
1	South-West Scotland	2007	374	2%
2a	West Scotland - South	2007	1661	9%
2b	West Scotland - Central	2007, 2008	561	3%
2c	West Scotland - North	2008	177	1%
3	Western Isles	2008	3396	17%
4a	North Coast	2008	344	2%
4b	Orkney	2008	8021	41%
5	Shetland	2006	1383	7%
6	Moray Firth	2007, 2008	1263	6%
7	East Coast	2007	2324	12%
		TOTAL	**19504**	

Table 7. The number of grey seals counted on the south-east coast of Scotland during the most recent (August 2007) harbour seal population monitoring/moult survey.

Region	2007
Tayside (Montrose to Newburgh)	108
Fife (Newburgh to Kincardine Bridge)	1771
Central (Upper Forth)	0
Lothian (Kincardine Bridge to Torness Power Station)	72
Borders (Torness Power Station to Berwick upon Tweed)	0
Total	**1951**

SEASONAL VARIATION IN GREY SEAL HAUL OUT COUNTS

A series of monthly counts of grey seals were carried out on the east coast of Scotland and NE coast of England as part of a BERR (now DECC) funded project in 2008 (McConnell et al. 2009). The monthly count totals are summarised in Table 9. The maximum total count was 6,498 in July; approximately double the other monthly counts. Much of this was due to a very high number of seals (2,756) counted at Lindisfarne (10km north of the Farnes). The distribution of seals by month is shown in Figure 6. The number of seals hauled out at the various sites varied between months with the maximum count at Abertay occurring in June, and the maximum count in the North East region and the Farnes occurring in July.

Table 8. Total counts of grey seals hauled out during monthly aerial surveys in April-September 2008. Note that the June survey omitted the Firth of Forth and the total was 5,643. The count for this month is adjusted upwards here by the average count in the Firth of Forth in the other five months (163).

Haulout region	April	May	June	July	August	September	Mean
North east Scotland	278	346	163	698	95	305	315
Abertay	980	1,001	2,037	1,609	866	1,663	1,359
Farnes	2,415	2,358	3,443	4,191	2,370	2,079	2,809
Total	**3,673**	**3,705**	**5,643**	**6,498**	**3,331**	**4,047**	**4,483**

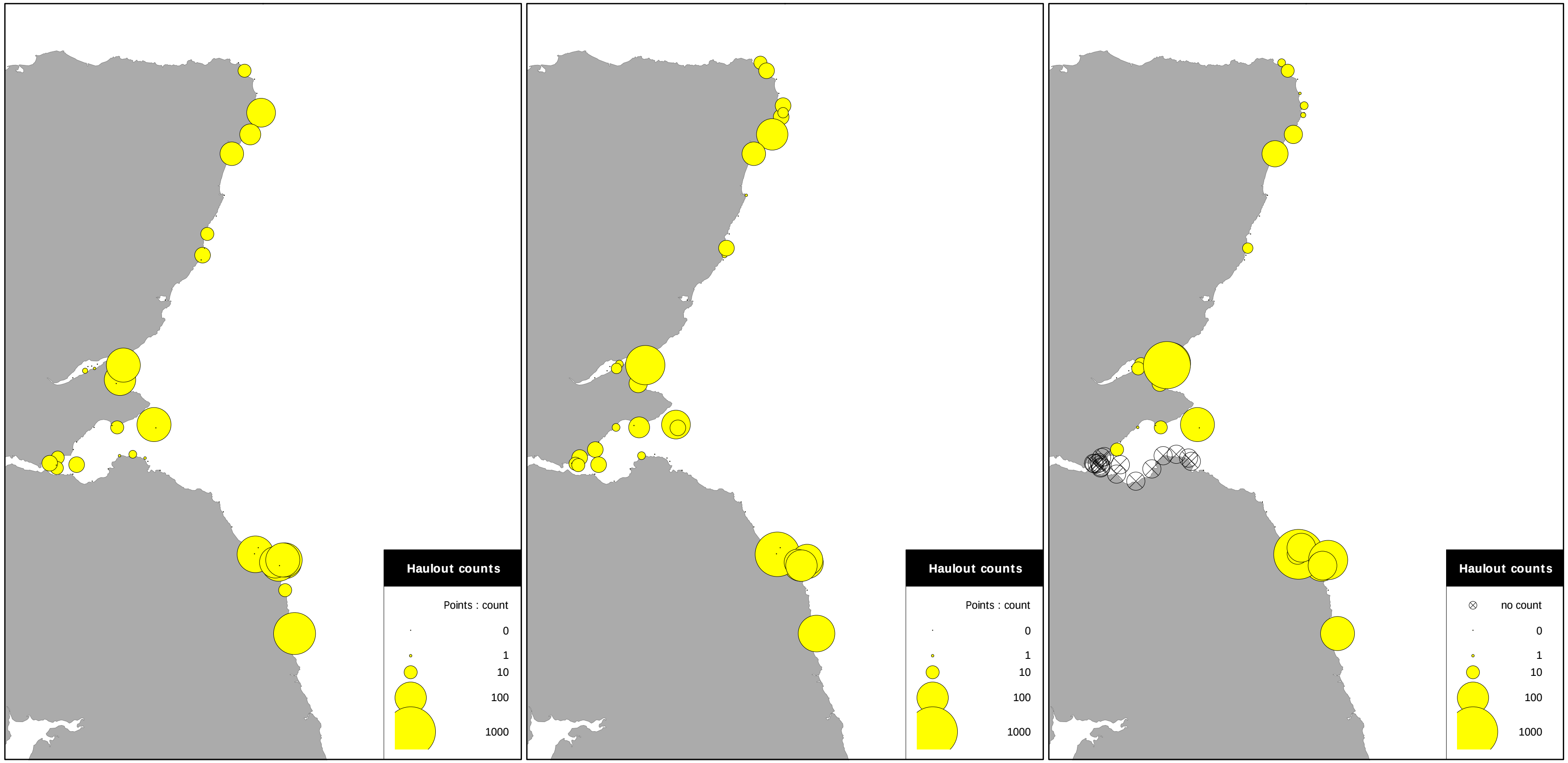
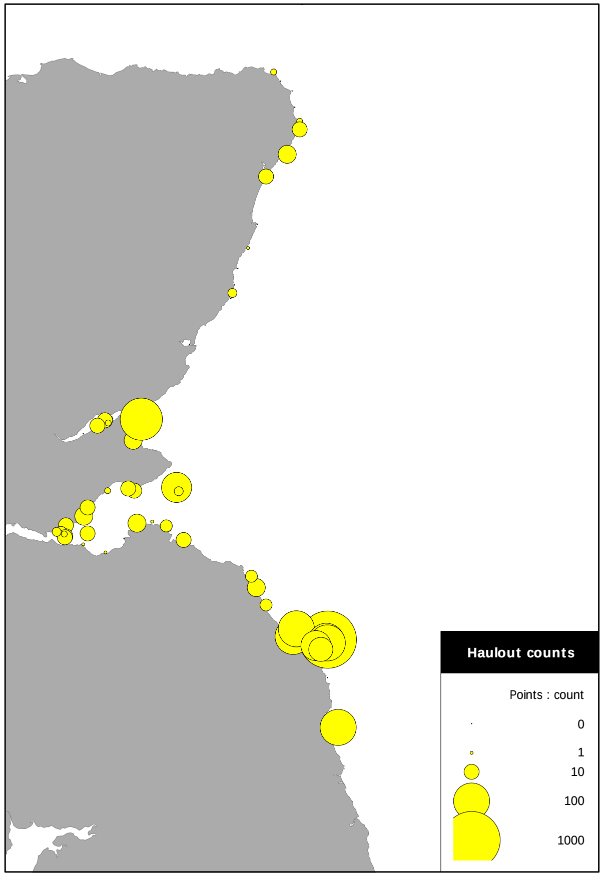
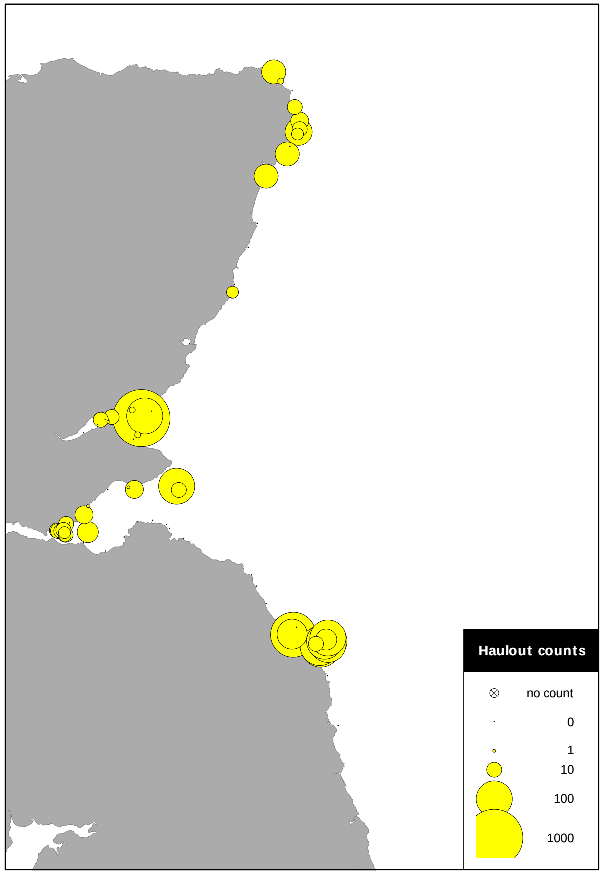


Figure 6. Monthly aerial survey counts in April-September 2008.


Haulout counts
Points : count
0
1
10
100
1000


Haulout counts
Points : count
0
1
10
100
1000


Haulout counts
no count
0
1
10
100
1000

APPROPRIATE REFERENCE POPULATION FOR GREY SEALS FOR IMPACT ASSESSMENT

Given the wide ranging nature of grey seals (see telemetry section of this report), defining an appropriate reference population for this area against which to assess the magnitude of any impacts is problematic. Seals known to be using the area around the proposed wind farm sites haul out at widely dispersed sites.

There is also the issue of having two ways of counting the population – pup production during the breeding season and numbers of hauled out animals during the harbour seal moult surveys in August. Pup production estimates are traditionally used to estimate the total size of the UK grey seal population but there is a lack of data to adequately link breeding populations with areas used for foraging and haul out areas throughout the rest of the year, therefore it is unknown how appropriate this may be at a local scale.

Total pup production for the closest breeding colonies (Isle of May and Forth Islands, Fast Castle and the Farnes) was 5393 pups in 2009 (Table 6). Using the ratio of pups to adults (calculated from the 2009 estimates for the total North Sea population) to be 2.59 (95% CI 1.73-3.69) adults per pup, (19900 adults (95% CI 13300-28200):7640 pups) gives an estimated local breeding population of 14047 (9330-19906) grey seals.

Seals counted around the coast at other times of year (e.g. grey seal counts made during August harbour seal surveys) could potentially be used to give an indication of the population size using a given area out with the breeding season. If data exists from telemetry studies to estimate the proportion of time seals spend at sea at the time the counts are made then these counts can be scaled up to provide a population estimate (Lonergan et al. 2010). However, the annual August harbour seal surveys don't cover the entire range of haul out sites relevant to grey seals which use the FTOWDG area – for example, the Farnes Islands are not covered by the annual August surveys. In summer 2008, grey seals were counted during a series of surveys which extended down the North East English coast. Using the total in August of 3331 (Table 9), and correcting for the proportion of seals hauled out calculated from telemetry data (0.34; 95% confidence interval 0.30-0.37), gives a population estimate for the region of 9797 (9002-11103) seals. This estimate cannot be repeated for years other than 2008 without also extending the August grey seal counts to the Farnes.

These analyses suggest that the number of grey seals using regional sites close to the proposed wind farm sites ranges between 9002 and 19906 depending on the time of year, and whether estimates are based on numbers hauled out in summer or breeding in winter.

SEAL TELEMETRY

SMRU has deployed telemetry tags on grey and harbour seals in the UK since 1988 and 2001, respectively. These tags transmit data on seal locations with the duration (number of days) of data varying between individual deployments. There are two types of telemetry tag which are associated with two types of data transmission. Data transmission can be through the Argos satellite system (Argos tags) or mobile phone network (phone tags). Both types of transmission result in location fixes, but data from phone tags comprise better quality and more frequent locations. Data from telemetry studies used in this report have been cleaned according to SMRU protocol (Russell et al. 2011). Location data resulting from Argos tags were then corrected for positional error using a linear Gaussian state space Kalman filter (Royer & Lutcavage, 2008; Jones et al. 2011). A buffer zone was generated which extends 100 km from the boundary of the potential wind farm developments. Data from a tagged animal are presented if a location was recorded anywhere inside the buffer zone during its deployment. It should be noted that in figures with location fixes, rather than tracks, there will normally be more location fixes for phone tags than for Argos tags. All locations on land have been excluded.

Seals move at faster speeds when travelling in comparison to foraging. Movements to foraging areas are directed (Thompson and Miller 1990) whereas when foraging, movements are slower and involve more turning. Thus based on speeds, locations can be classed into slow and fast movements (McConnell et al. 1999) to indicate potential foraging and travelling locations, respectively. Here we have used a threshold of 0.5 ms^{-1} to classify locations into potential foraging and travelling locations. We use this threshold following work by McConnell et al. (1999) on grey seal movements. At-sea observations (Thompson et al. 1991), sediment type and diving behaviour indicate that these slow speed locations reflect foraging locations in grey seals (McConnell et al. 1999). For illustration purposes, slow speeds are plotted on top of fast speeds so that any potential foraging areas are not concealed by transit routes through that area. This plotting order should be taken into account when interpreting these figures. Areas of slow movement near haulouts may reflect activity associated with the haulout, such as socialising, thus locations of haul outs have been indicated on the maps. In previous studies, slow locations within 2 (Thompson et al. 1994) and 10 km (McConnell et al. 1991) of haulouts were omitted as potential foraging locations for harbour and grey seals respectively. However, it was recognised that this exclusion may have caused an underestimation of the foraging locations (McConnell et al. 1991).

SEAL TRACKS

GREY SEALS

Adults

There were 92 tagged grey seals, of age one year and above, which entered the buffer zone. The resulting locations (Figure 7a and Figure 8a) and tracks (Figure 7b and Figure 8b) are shown, with each colour representing a different tag. These figures show the locations and movements of the seals whilst tagged (Figure 7 is deliberately zoomed out to show the wide ranging nature of grey seal tracks;

Figure 8 shows the locations and movements within the proposed wind farm sites). Locations associated with slow and fast movements, which may indicate foraging and travelling, respectively are shown in Figure 9. Several areas of concentrated slow movement can be seen that could represent foraging hotspots, although areas of slow movement close to shore or around islands and rocky outcrops may also represent resting. These tags were deployed in various locations and years (1989 - 2008), with a median tag duration of 129 days (range: 3 - 253 days). Most of the tags were deployed within the buffer zone (84) but some seals were tagged elsewhere including the Orkney Islands. It should be noted that the majority of the tags (79) were Argos tags.

(a) (b)

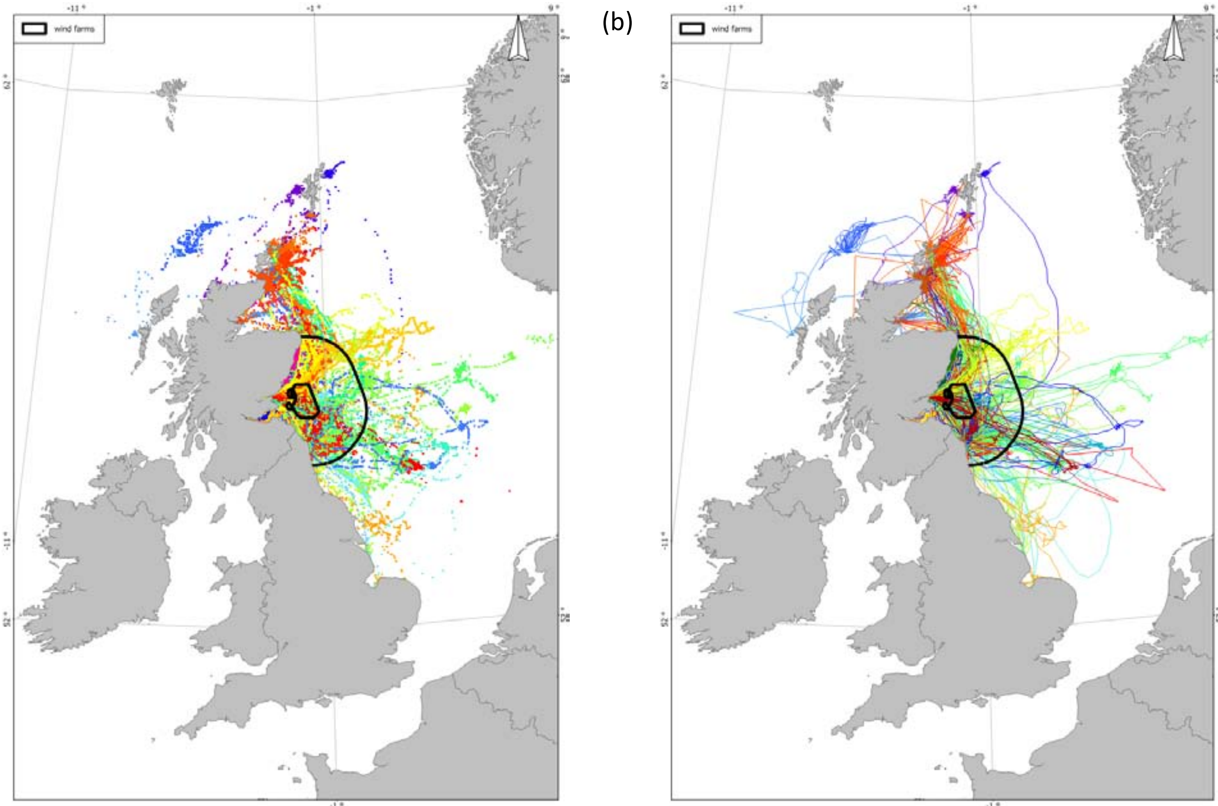


Figure 7 The locations (a) and associated tracks (b) of adult grey seals which have entered the 100 km buffer zone.

(a) (b)

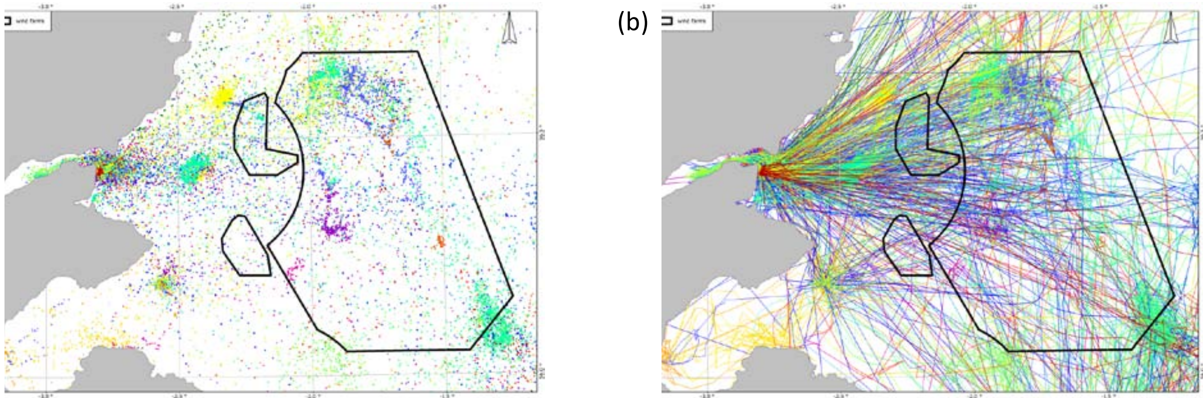


Figure 8 The locations (a) and associated tracks (b) of adult grey seals around and inside the potential wind farm areas.

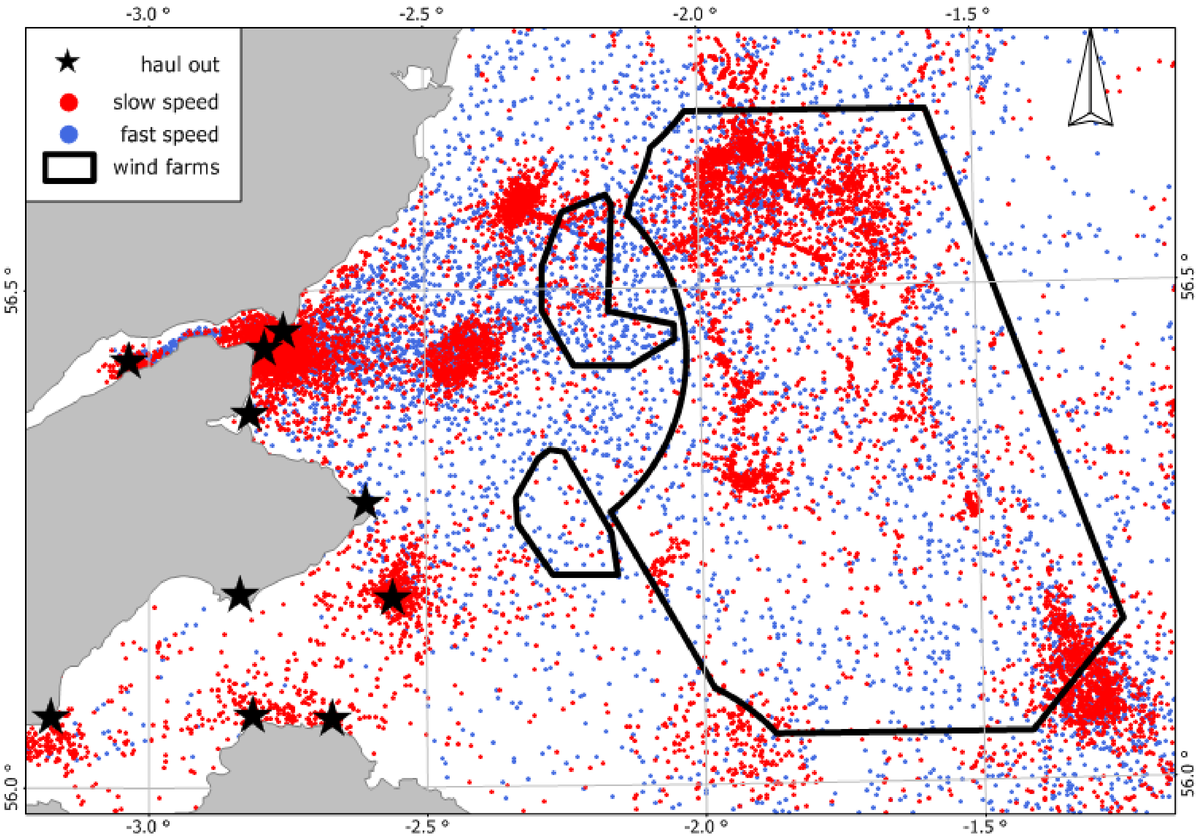


Figure 9. The locations of adult grey seals around and inside the potential wind farm areas with locations classified by speed. This includes data from both Argos and phone tags.

Pups

There were 30 grey seal pups tagged (Argos) at breeding colonies within the buffer zone. Nine of these pups were tagged on the Farne Islands (1993 - 1994) and 21 on the Isle May, East Scotland (2001 - 2002). The resulting locations (Figure 10a and Figure 11a) and tracks (Figure 10b and Figure 11b) are shown, with each colour representing a different tag. These figures show where these pups have been located and their movements whilst tagged (Figure 10), and also only locations and movements within the potential wind farm areas (Figure 11). Locations associated with slow and fast movements, which may indicate foraging and travelling respectively, are shown in Figure 12. Movements were typically recorded for a few months (median duration: 90 days) but tag duration varied between 40 and 304 days.

(a) (b)

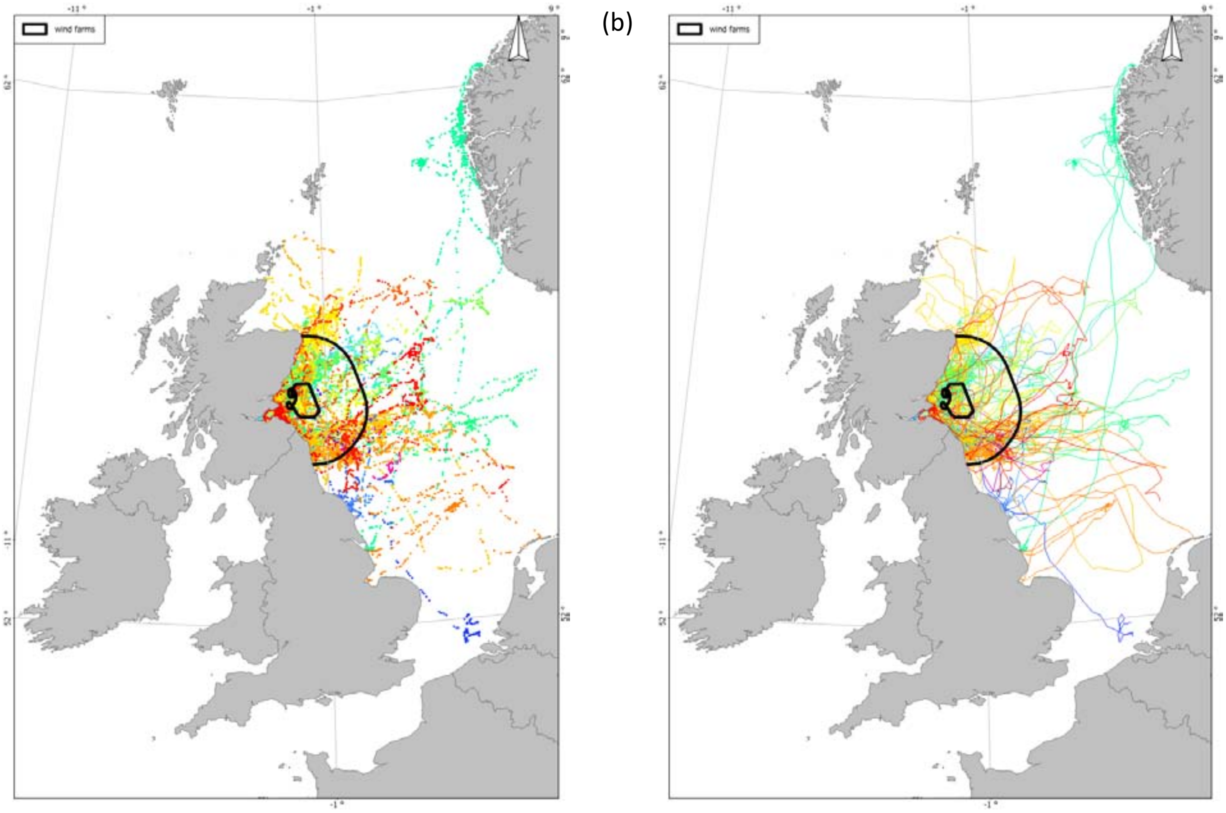


Figure 10. The locations (a) and associated tracks (b) of grey seal pups which have entered the 100 km buffer zone.

(a) (b)

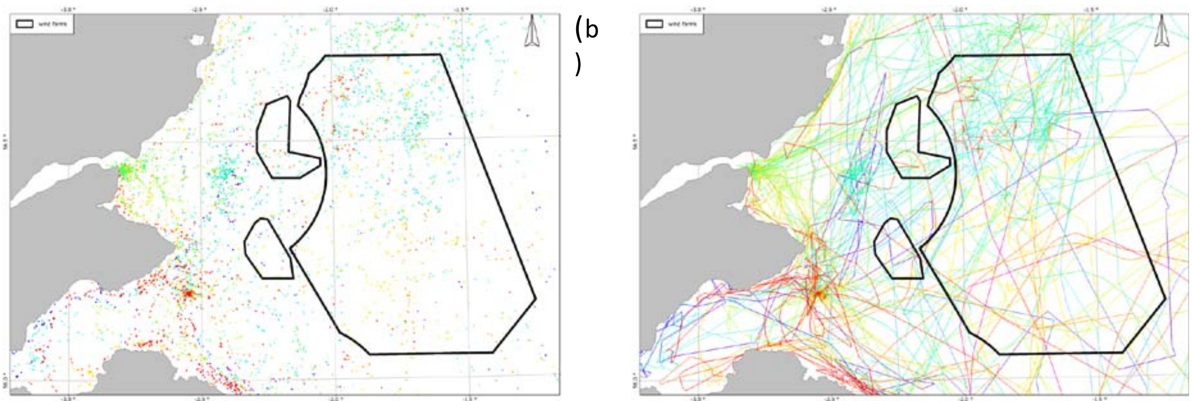


Figure 11. The locations (a) and associated tracks (b) of grey seal pups around and inside the potential wind farm areas.

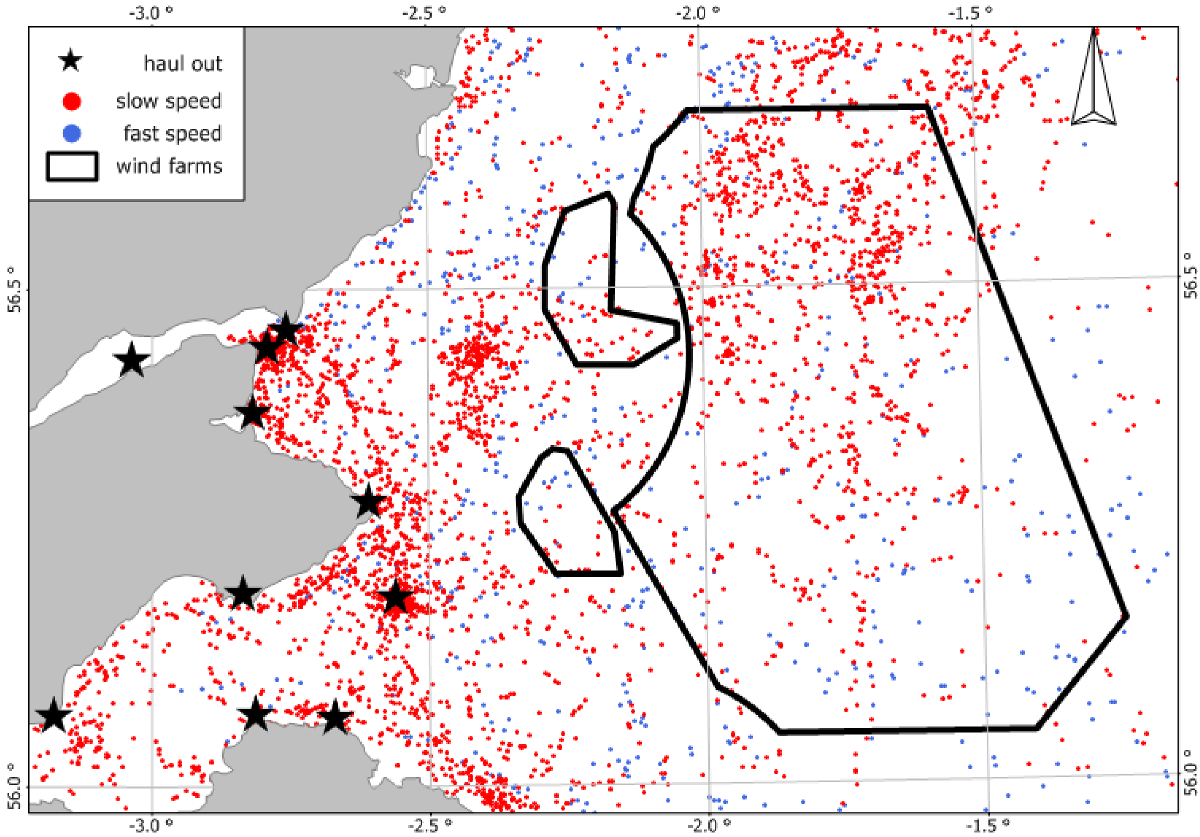


Figure 12. The locations of grey seal pups around and inside the potential wind farm areas with locations classified by speed.

Harbour seals

Adults

Pre 2011

There were 31 tagged harbour seals, of age one year and above, for which there are locations inside the buffer zone. All of these animals were tagged within the buffer zone. Of these 31 tags, 21 were Argos and ten were phone tags. The resulting locations (Figure 13a and Figure 14a) and tracks (Figure 13b and Figure 14b) are shown, with each colour representing a different tag. These figures show where these seals have been located and their movements whilst tagged (Figure 13), and also only locations and movements within the potential wind farm areas (Figure 14). Locations associated with slow and fast movements, which may indicate foraging and travelling respectively, are shown in Figure 15. These tags were deployed in various locations and years (2001 - 2008), with a median tag duration of 111 days (range: 12 - 183 days).

(a) (b)

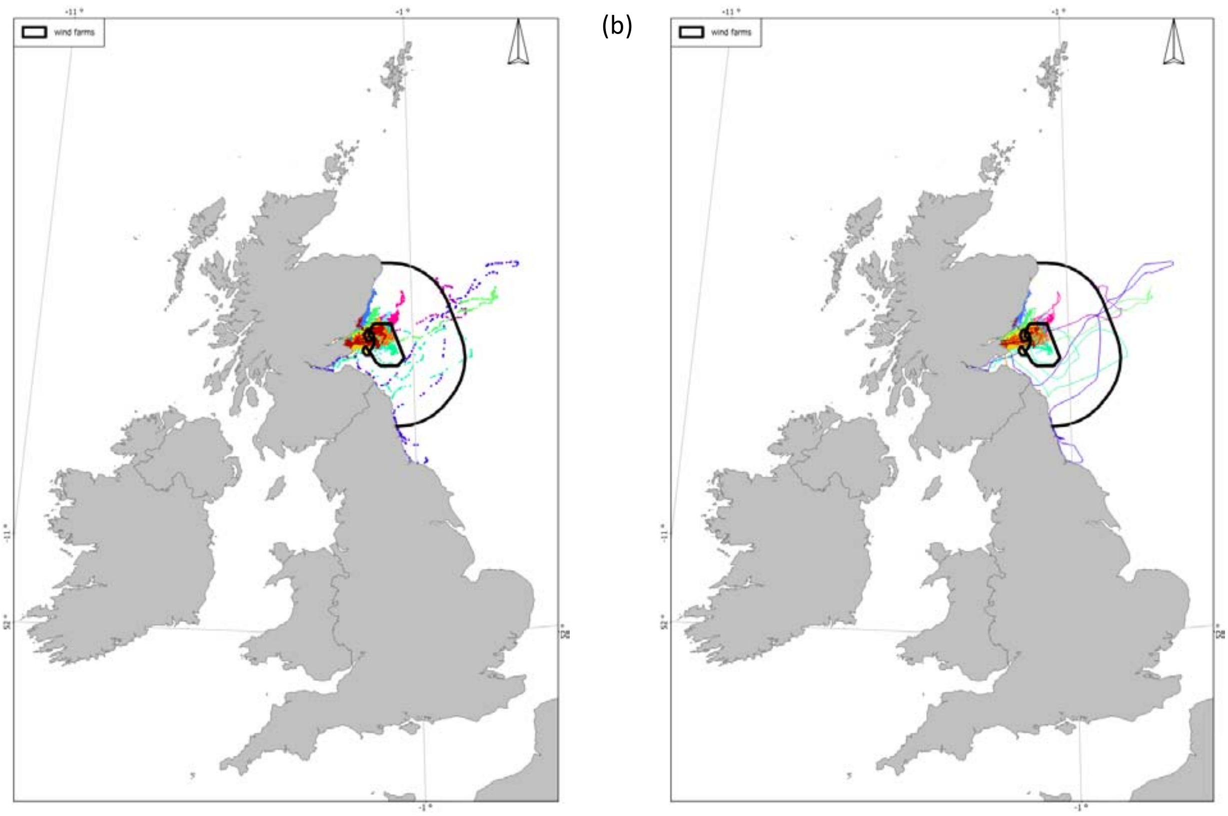


Figure 13. The locations (a) and associated tracks (b) of adult harbour seals (2001 - 2008) which have entered the 100 km buffer zone.

(a) (b)

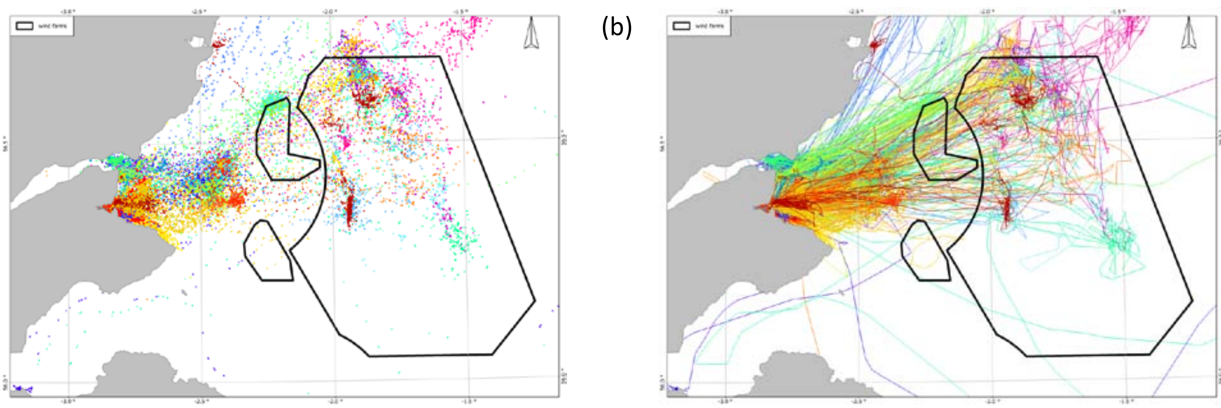


Figure 14. The locations (a) and associated tracks (b) of adult harbour seals (2001 - 2008) around and inside the potential wind farm areas.

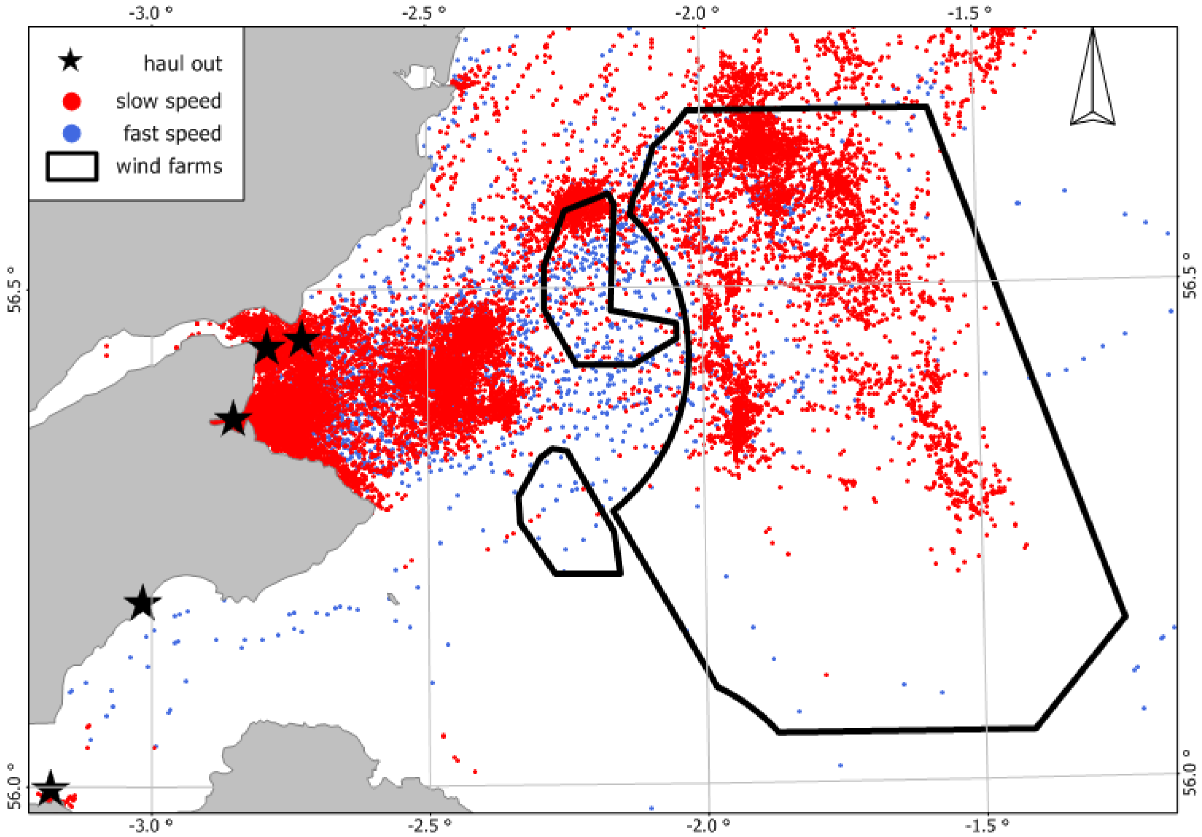


Figure 15. The locations of adult harbour seals (2001 - 2008) around and inside the potential wind farm areas with locations classified by speed. This includes data from both Argos and phone tags.

2011

Five phone tags were deployed in April 2011 on harbour seals in the Eden Estuary. Figure 16 shows the resulting locations and tracks. Table 9 gives the duration in days of each of the tag deployments. Locations associated with slow and fast movements, which may indicate foraging and travelling, respectively are shown in Figure 17. Although some locations near to haul outs may indicate activity associated with the haulout, it should be noted that some seals did not travel far from haulouts for the duration of tagging and these animals must have been foraging within the region they occupied.

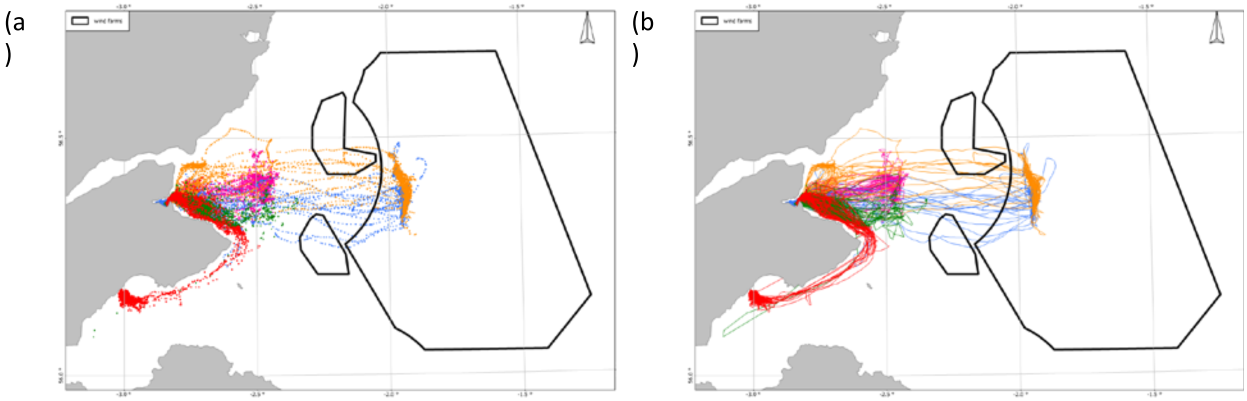


Figure 16. The locations (a) and associated tracks (b) of adult harbour seals (tagged in 2011) around and inside the potential wind farm areas.

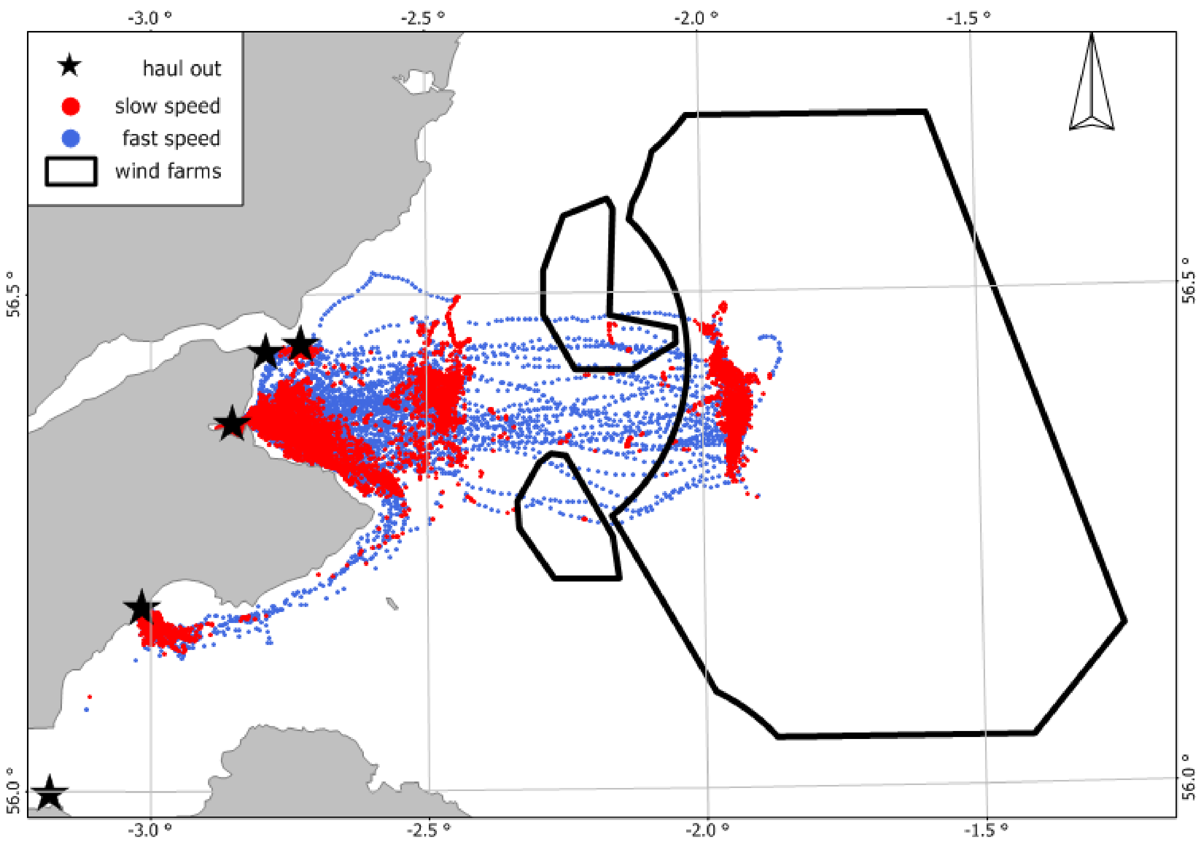


Figure 17. The locations of adult harbour seals (2011) around and inside the potential wind farm areas with locations classified by speed.

Table 9. The duration of telemetry tags deployed in 2011 in the Abertay area.

Tag reference	Duration (days)
A	132
B	134
C	116
D	143
E	151

Pups

Very few harbour seal pups have been tagged in the UK, and none in the East coast of Scotland. There were no locations of tagged harbour seals pups in the buffer region.

SAC CONNECTIVITY

The tracks shown in the Figures in the previous section represent a large number of animals tagged at SAC sites which have seals named as primary or qualifying features. In fact, all of the harbour seals were tagged at the Firth of Tay and Eden Estuary SAC (harbour seals are a primary reason for this site selection). Individual harbour seals show a very high degree of site fidelity, with all seals travelling relatively locally to forage and returning to the SAC to haul out. On a few occasions individual seals travelled up the Forth and along the south Fife coastline, hauling out at various places along the coast. One individual (in 2011) spent a large amount of time hauled out at Methil Harbour (Figure 17) making multiple trips along the coastline from there to the Eden Estuary and back, foraging near to the haul out site and spending very little time offshore. One seal travelled up the east coast to the Aberdeenshire coastline and another travelled south to the Northumberland coast (Figure 13). Harbour seals tagged at the Firth of Tay and Eden Estuary SAC did not visit any other harbour seal SACs during the tag deployment period.

Grey seals present within the buffer zone also travelled within the vicinity[1] of several SACs (with grey seals named as the primary reason for site designation) throughout the duration of the tag deployment period:

- Berwickshire and North Northumberland Coast - 56 seals
- Isle of May – 31 seals
- Faray and Holm of Faray, Orkney - 4 seals
- North Rona - 1 seal
- Humber Estuary - 3 seals

[1] Seal tracks were visually examined using GIS and were included in these totals if the interpolated tracks passed within 1km of the designated site.

SEAL DENSITY

INTRODUCTION

Telemetry data gives information on where a sample of tagged animals go and what areas of land and sea they use. If we assume this sample is representative of the population as a whole, this information can be combined with estimates of total population size to provide estimates of total population usage of, or estimated density in, a particular area. This study combined the telemetry data and haul out counts described in previous sections to produce maps, by species, of estimated at-sea usage in the area surrounding the FTOWDG proposed wind farm developments.

The method used for this is based on a development of Matthiopoulos et al.'s (2004) method. Full details of the methodology used to produce these maps are provided in Appendix One: seal usage maps.

GREY SEAL USAGE

Figure 18 shows estimated at-sea spatial usage of grey seals around the FTOWDG proposed development sites with standard deviation denoted by white contour lines. The map can be interpreted as the average number of seals in each 5km^2 grid square at any point in time. For example, a green square denotes that, on average, between 1 and 5 grey seals will be within that grid square at any point in time. A red square denotes that over 50 animals will be in that grid square at any point in time.

Within the study area the largest aggregations of high usage are located at the mouth of the Firth of Tay and near Berwick-upon-Tweed. Possible offshore foraging patches can also be seen throughout the region, with an aggregation of high usage on the northern boundary of the Firth of Forth (FoF) proposed wind farm development area (at Scalp Bank). There is also an area of high usage at Marr Bank, covering an area from NW to SE towards the south eastern corner of the FoF site. These areas of high usage generally correspond to the areas of slow at sea locations predicted to be indicative of foraging effort (Figure 9).

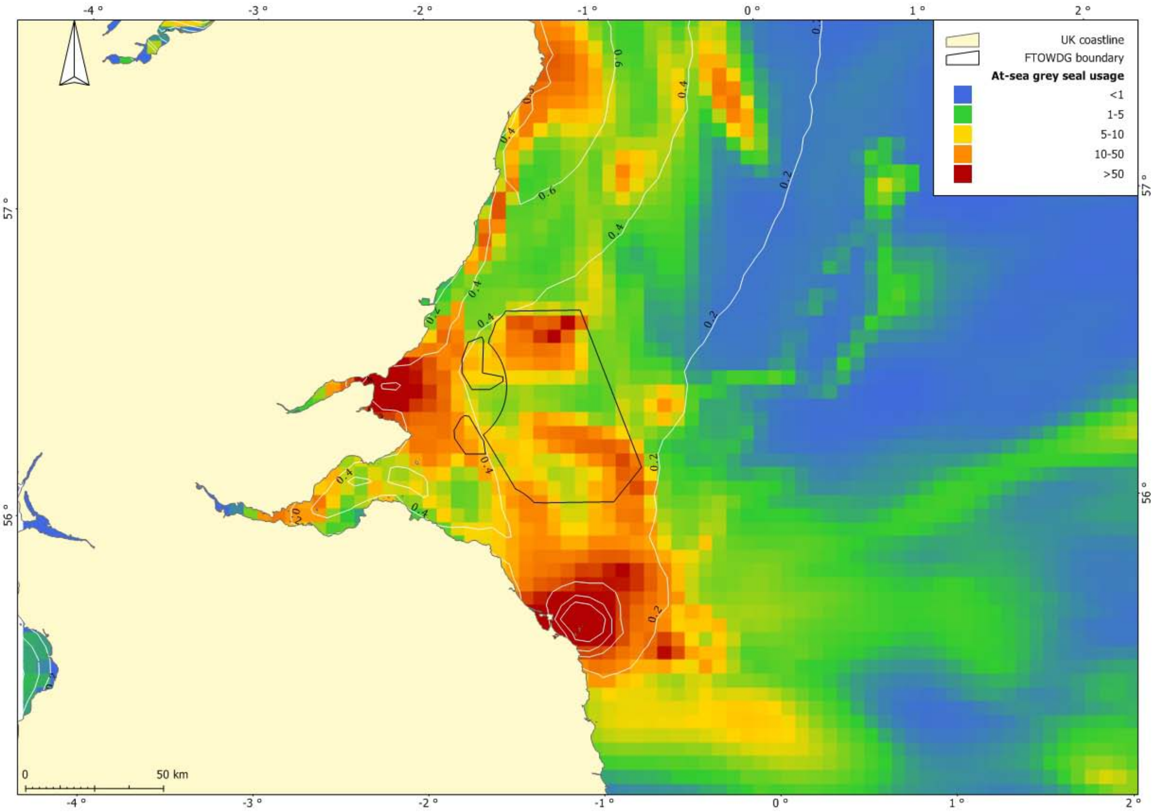


Figure 18. Estimated grey seal at-sea usage around the FTOWDG proposed development sites. White contours show standard deviation from mean usage as a measure of uncertainty

HARBOUR SEAL USAGE

Figure 19 shows estimated at-sea spatial usage of harbour seals around the FTOWDG proposed development sites with standard deviation denoted by white contour lines. Usage extends out from the haul-out sites located at the mouth of the Firth of Tay to areas of concentrated usage which are likely to be offshore foraging areas. These areas are between the haul out sites and the Inch Cape site, on the north tip of the Inch Cape site and in the northern part of the Firth of Forth site (over Scalp Bank). There is also a patch of increased usage on Marr Bank in the south eastern part of the Firth of Forth site.

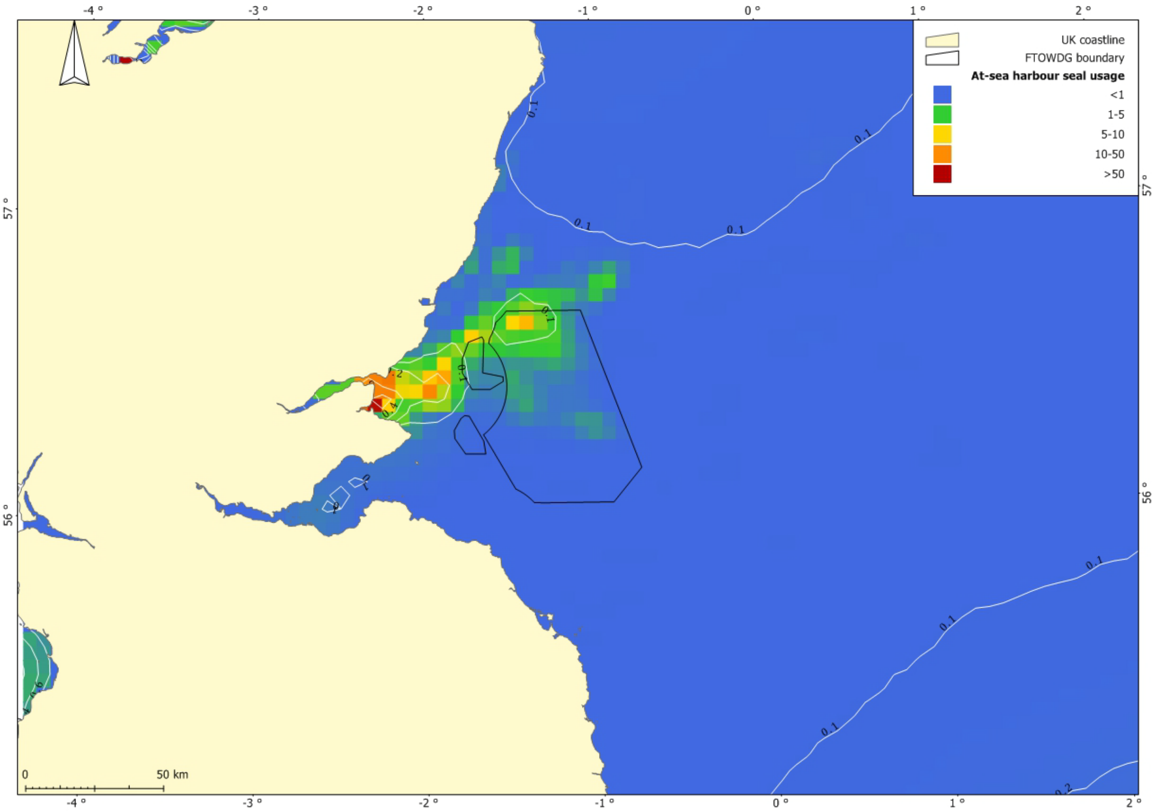


Figure 19. Estimated harbour seal at-sea usage around the FTOWDG proposed development sites. White contours show standard deviation from mean usage as a measure of uncertainty.

USAGE MAPS AS AN INPUT INTO IMPACT ASSESSMENT

These usage maps provide spatially explicit density estimates which will be used in the quantitative noise impact assessment – they will be used as a base layer in the simulation of seal exposure to construction noise and will be combined with the outputs from the noise modelling work undertaken by Subacoustech for the FTOWDG. The results of this work will be detailed in a subsequent report.

SEAL TRANSIT

The figures and analyses presented in the telemetry and density sections provide an indication of the areas where seals spend most of their time, which is a good proxy for how important an area may be. However, the routes that seals take to transit between haul out sites and foraging areas are also important although, in relative terms, they spend much less time there. Understanding how these movements vary spatially is important in understanding the implications of activities which may potentially displace animals from preferred routes, or impact upon seals using these areas. The figures showing the tracks of tagged seals (e.g. Figure 8 and Figure 14) show the pattern of seal movements but because all tracks are mapped on top of each other, individual features of tracks are often obscured and it is difficult to visually separate out areas which are particularly important for transit.

In order to identify areas important for directed movement we carried out a separate analysis. A 5km grid was overlaid across the region and seal tracks were divided up into segments, with each segment starting when the animal entered a grid cell and ending when it left it. Each segment was then represented by a line of standard length, centred at the middle of the appropriate grid cell and running in a line from the start point of the segment to its end point. Separate plots were drawn for grey (Figure 20) and harbour (Figure 21) seals. Each cell shows the total number of transits across it, and the distribution of the orientations of these crossings. Using standard lengths for the representations means that all transits are equally visible but sacrifices information on the relative speeds of different movements. While making the length proportional to speed would convey some of this information, it would make the slower movements, which generally represent longer periods within the cells, less visible.

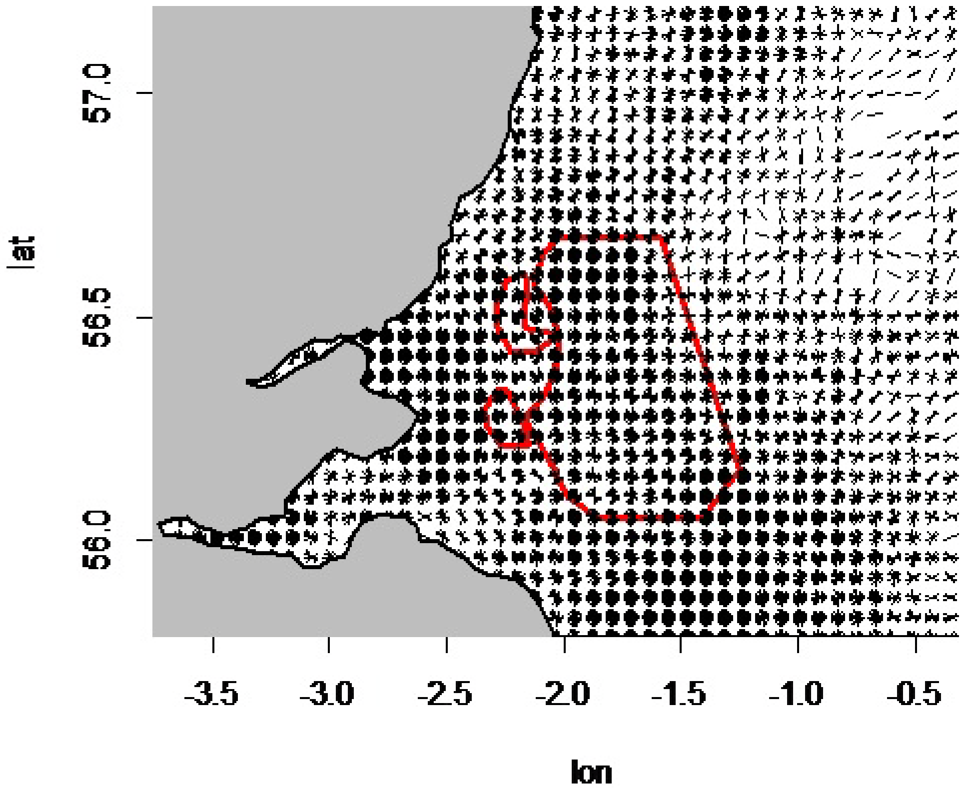


Figure 20. Plot of grey seal track orientation – the direction of each seal transit across each 5km grid cell is shown. Each line represents a single crossing of the grid cell. Windfarm sites are as in Figure 1.

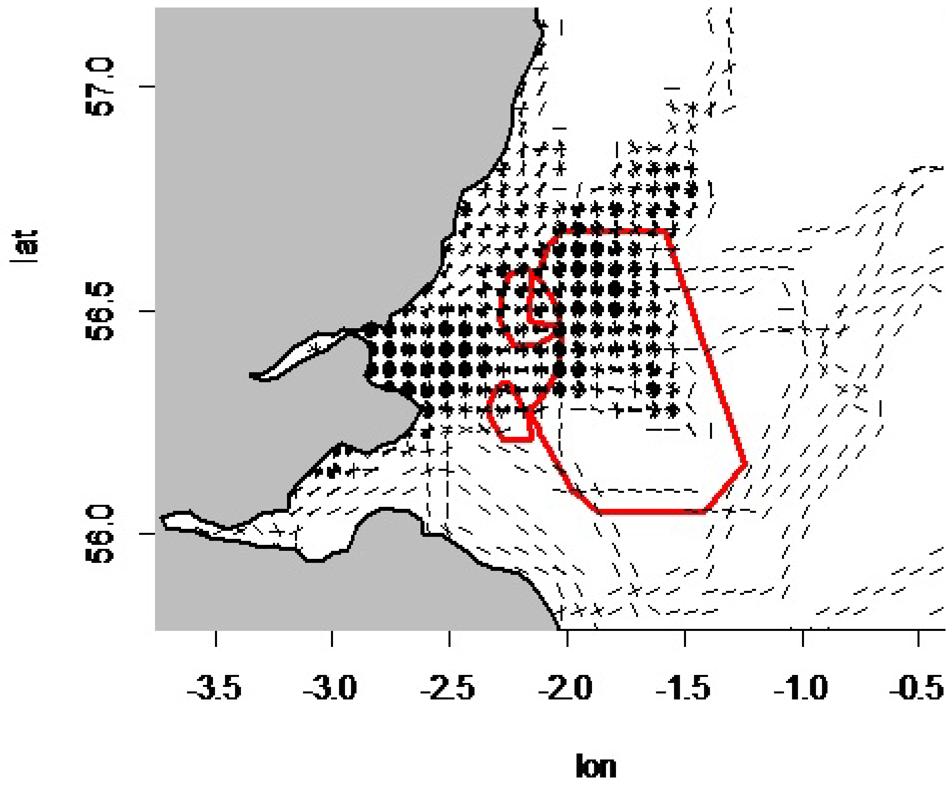


Figure 21. Plot of harbour seal track orientation – the direction of each seal transit across each 5km grid cell is shown. Each line represents a single crossing of the grid cell. Windfarm sites are as in Figure 1.

These figures allow us to distinguish between areas of directed travel and non-directed movement. Cells which appear to have more circular shapes within them represent many tracks crossing the cell in different directions, suggesting random (or non-directed) movement. Cells containing parallel lines have a much less circular appearance and represent areas where the tracks are more indicative of directional travel. The intention is for these figures to be examined in combination with the figures in the previous section to build up a complete picture of how seals use the area. There is a very large amount of data for grey seals, resulting in many tracks which makes patterns difficult to discern. However, there appear to be few areas of purely directional movement (Figure 20). There is some indication of an area between offshore foraging hotspots and areas close to shore – the area which encompasses the Inch Cape site. There is also a region south of the NnG site, between the NnG site and the coast, which may represent an area used for travelling between haul out sites. In the harbour seal plot (Figure 21), the area of transit between haul out sites and offshore foraging hotspots extends from the Inch Cape site southwards to about halfway down the NnG site. Taken together with the plots in the earlier sections, showing hotspots of density and areas of fast and slow movement, these maps suggest that both these sites (Inch Cape and NnG) may cover important travel routes for seals.

SEAL DIET

Assessing the species composition of seal diet is challenging; feeding events may occur underwater or many kilometres from land and are rarely observed. Scat analysis is one method which can be used effectively. It is not suitable for areas where seals forage far from shore (when passage rate is less than the time it will take for the animal to return to shore after a foraging trip), but it is suitable, and widely used, for both UK seal species. Scats can be collected from sites where seals come ashore and the ear bones of fish (otoliths) and beaks of cephalopods (squid and octopus) recovered and used to identify the species and size of prey consumed.

A number of studies have looked at seal diet in the region (see Summary in Table 10).

Table 10. A summary of the seal diet studies relevant to the FTOWDG area.

Seal species	Sites sampled	Time period	Reference
Grey seal	Isle of May Farne Islands	1983-1988	Hammond and Prime 1990
	Abertay Isle of May Farne Islands	1996-1998	Hall et al. 2000
	Abertay Sands Eden Estuary Isle of May Fast Castle Farne Islands	2002	Hammond and Grellier 2006
Harbour seal	St Andrews Bay Firth of Tay	1998-2003	Sharples et al. 2009

METHODOLOGICAL APPROACH

Diet composition for both grey and harbour seals in the Central North Sea was estimated using scat analysis. Scats were collected on a monthly or quarterly basis from the haulout sites shown in Figure 21. Identifiable hard parts from prey items (fish otoliths (ear bones) and cephalopod beaks) recovered from scats were identified and measured. Otoliths recovered from grey seal scats were graded according to the amount by which they had been digested. Species- or grade-specific digestion coefficients (to account for partial digestion) and recovery rates (to account for complete digestion; Grellier and Hammond 2006; Middlemas et al. 2004) were then applied. Using these corrected measures, the weight of prey associated with each structure was estimated; these estimates were then summed by species enabling seal diet to be expressed as the percentage contribution of each prey species, by weight.

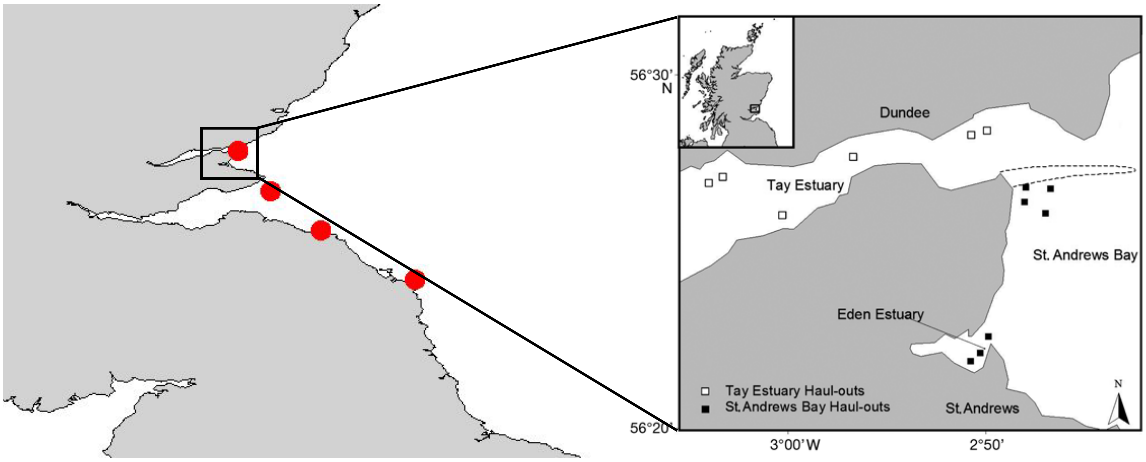


Figure 22.Map showing the grey seal haulout sites from which scat samples were collected (from south to north these are the Farne Islands, Fast Castle, Isle of May and Abertay Sands and the Eden Estuary; taken from Grellier et al. in prep.) and (inset; taken from Sharples et al. 2009) the harbour seal haulout sites from which scat samples were collected.

GREY SEAL DIET

Central North Sea 2002

356 scats containing hard parts were collected at Abertay Sands and the Eden Estuary, the Isle of May, Fast Castle and the Farne Islands in 2002.

Sandeel dominated the diet in all seasons in the Central North Sea in 2002, contributing between 53 and 76% to the diet, by weight, in each quarter (Figure 22). Gadoids were the second biggest contributor in each season after sandeel; 35% of the diet was made up by gadoids (mostly haddock and cod) in quarter 1. In quarter 2 gadoids (mainly haddock and whiting) contributed 15% while flatfish (mainly plaice) and benthic species (mainly dragonet) contributed 10% and 9%, respectively. In quarter 3, gadoids (mainly haddock) contributed 12% while in quarter 4 gadoids (28%; mainly haddock and cod) and benthic species (13%; mainly short-spined seascorpion) were the next most important contributors after sandeel.

Re-analysis of grey seal diet data collected in the Central North Sea in the 1980s and 1990s

A re-analysis of grey seal diet data collected in the Central North Sea in 1983-1988 (Hammond and Prime 1990) and 1996-1998 (Hall et al. 2000) was carried out using the same methods, correction factors (Grellier and Hammond 2006) and allometric equations that were used for analysis of the 2002 data (Hammond and Grellier 2006; Grellier et al. in prep.) but with the following differences:

1. The otolith measurement of choice in both previous studies (1980s and 1990s) was thickness (although length and width were also measured some of the time). Where only otolith thickness had been measured, length and width were estimated from length-thickness and width-thickness relationships fitted to data on partially digested otoliths.

2. None of the otoliths in either of the previous grey seal diet studies (or that on harbour seals) were graded for amount of digestion they had undergone therefore species-specific digestion coefficients (Grellier and Hammond 2006) were used. The sensitivity of diet composition estimates to using species-specific, rather than grade-specific, digestion coefficients was investigated (Grellier 2006) and only slight differences in diet composition estimates would be expected if it had been possible to apply grade-specific digestion coefficients to these data; less sandeel and more of most of the other main prey species.

Differences in results from those generated by previous analyses (Hammond and Prime 1990; Hall et al. 2000) were expected because of the use of new digestion coefficients (Grellier and Hammond 2006), recovery rates for the first time (Grellier and Hammond 2006) and new relationships between otolith size and fish size (primarily from Leopold et al. 2001). The re-analysed diet composition estimates for the 1980s and 1990s should be considered as the best estimates, and previous results (Hammond and Prime 1990; Hall et al. 2000) disregarded.

Central North Sea 1983-1988

236 scats containing hard parts were collected at the Isle of May and the Farne Islands in the 1980s and processed (Figure 21).

Grey seal diet in the Central North Sea in the 1980s was dominated by cod and sandeel (Figure 22). Gadoids (mostly cod but also some whiting) dominated in the first quarter of the year with benthic prey (dragonet and unidentified Cottidae) being the next most important contributor. Sandeel dominated in both Q2 and Q4 (no data were collected in Q3) with cod being the next most important contributor in both quarters.

Central North Sea 1996-1998

385 scats containing hard parts were collected at Abertay, the Isle of May and the Farne Islands in the 1990s (Figure 21).

Grey seal diet in the Central North Sea in the 1990s was also dominated by sandeel and cod (Figure 22). Together these two prey species made up 75% or more of the diet in all four quarters. Sandeel dominated in the first three quarters of the year while cod dominated in quarter 4. Cod did not really feature in the diet in Q3 but the proportion of haddock (and flatfish) increased. The proportion that benthic species made up was only notable in Q4.

Comparison of the three time periods

Sandeel contributed more to the diet of grey seals in the Central North Sea in the 1990s (60%) and 2002 (62%) than in the 1980s (47%; Figure 22). Gadoids were almost as important as sandeel in the diet in the 1980s, contributing an average of 43% by weight per quarter. The contribution of gadoids to the diet was greatest in winter in all three time periods (70% in quarter 1 of the 1980s, 53% in quarter 4 of the 1990s, and 36 and 28% in quarter 1 and quarter 4 of 2002, respectively). Cod was the most important of the gadoid prey in the 1980s and 1990s, while haddock was most important in 2002.

The size of fish consumed by grey seals

The lengths of cod, whiting and sandeel consumed by grey seals in the Central North Sea were estimated from the size of the otoliths recovered from scats (Grellier et al. in prep).

Cod consumed by grey seals in 2002 were significantly smaller than those consumed in both the 1980s and 1990s. However, the cod consumed in the 1990s were significantly larger than those consumed in the 1980s.

Whiting consumed in 2002 were significantly smaller than those consumed in the 1990s which, in turn, were smaller than those consumed in the 1980s.

Similarly, sandeel consumed in the Central North Sea in 2002 were significantly smaller than those consumed in the 1990s which, in turn, were smaller than those consumed in the 1980s.

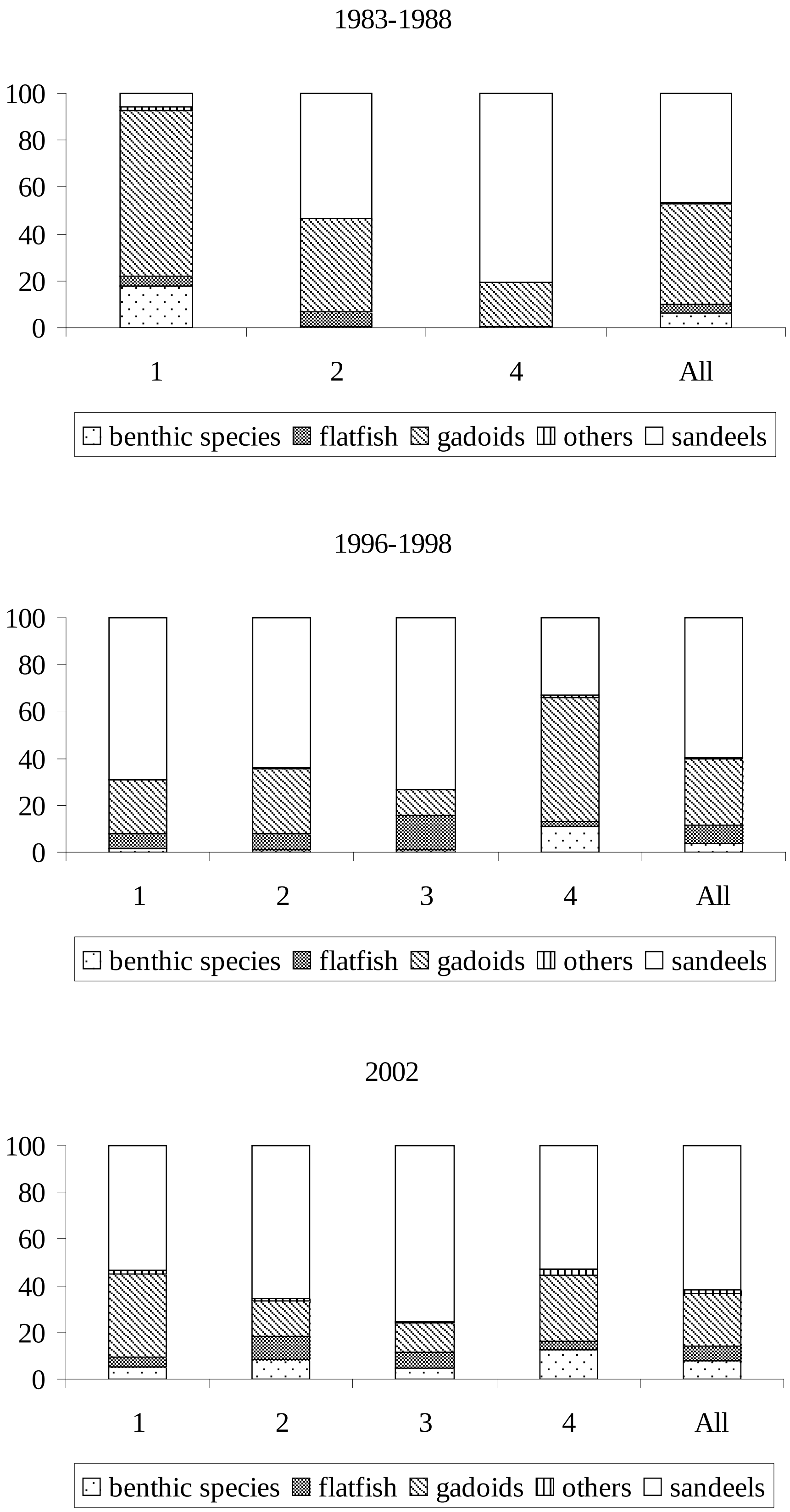


Figure 23. Between and within year variation in grey seal diet composition (shown as % by weight and expressed by prey type) in the Central North Sea (taken from Grellier et al. in prep).

Diet in St Andrews Bay and the Firth of Tay in 1998-2003

Harbour seal haul-out sites in St. Andrews Bay and the Firth of Tay (Figure 21) were visited 162 times between February 1998 and July 2003 (Sharples *et al*. 2009). 809 scats were collected, 749 (92.6%) of which contained fish otoliths and/or cephalopod beaks: 88401 otoliths and beaks were recovered and 31 different prey species identified (Sharples *et al.* 2009).

St Andrews Bay

Ten prey species made up more than 95% of the total prey consumed by mass in any year or season. Sandeel were the dominant prey across all quarters and years, contributing 71 to 77% by weight in each year. The contribution of sandeel was highest in Winter and Spring (81 to 94% of the diet) and lower in Summer and Autumn (63%; Figure 24). The reduced sandeel consumption in Summer and Autumn was compensated for primarily by higher percentages of gadoids in Autumn, flatfish in Summer and Autumn and pelagic fish (herring) in Summer. The dominant gadoid in the diet was whiting, followed by cod. Flatfish consumed were primarily common dab, flounder and plaice; however, a large number of flatfish otoliths were too small or eroded to identify to species. Salmon contributed little to the diet during Spring, Autumn and Summer, averaging 1.27% (range = <0.01 to 3.39).

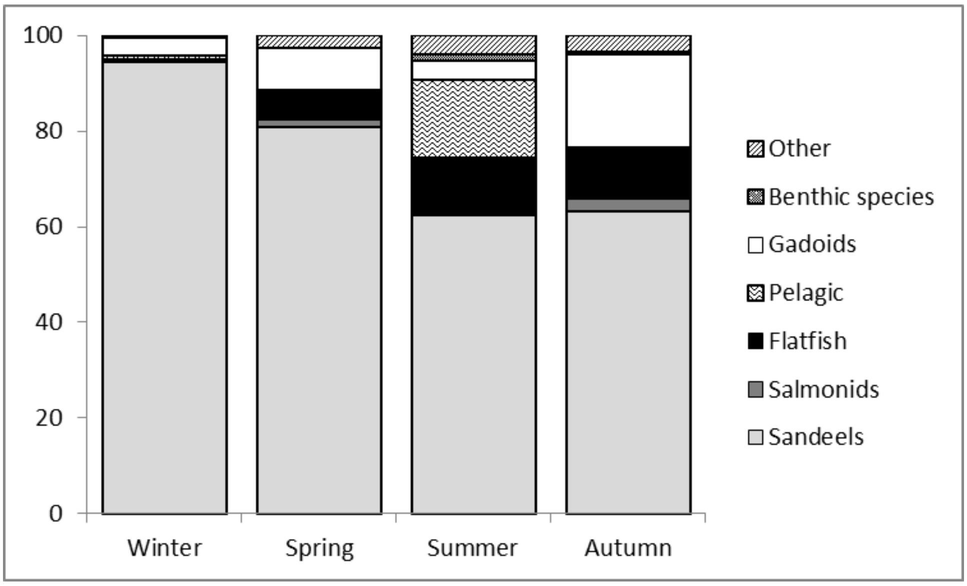


Figure 24. Average seasonal percentage by weight of each prey type in the diet of harbour seals in St Andrews Bay (reproduced using data presented in Sharples et al. 2009).

Firth of Tay

The diet of harbour seals that hauled out in the Firth of Tay (Figure 24) was markedly different to that in St Andrews Bay (Figure 25). Salmonids were the dominant prey type, except in Winter, comprising an estimated 78% of the diet in Spring (salmon 32%, smelt 17% and sea trout 28%), 47% in Summer (salmon only) and 40% in Autumn (sea trout only), but all with very wide confidence intervals. All salmon otoliths were recovered from only 5 scats and all sea trout otoliths from only 2 scats. Of the 52 salmon otoliths recovered, 21 were estimated to come from fish no greater than 11cm in length; these were likely to be salmon smolt leaving the river. The 29 otoliths from fish with estimated lengths between 30 and 65cm were likely to be returning one-sea-winter grilse. Two otoliths were estimated to be from fish >85cm; these were likely to be returning multi-sea-winter adults. The weights estimated from otoliths in these size classes were in the proportions <2, 75 and 23%, respectively. These are equivalent to the proportions of each size class consumed. Note that estimates of length and weight are subject to uncertainty so the above calculations are approximate only. However, consumption of smolts, which have a low survival rate (8.9%, Jonsson et al. 2003), is clearly minor; most of the salmon consumed were in the size range taken by the rod and line fishery for mature fish. In contrast to St. Andrews Bay, harbour seals that hauled out in the Firth of Tay were estimated to consume substantial quantities of salmon in Spring and Summer (50 and 96t, respectively) but with very wide confidence intervals. Sandeel, flounder and whiting were the only other prey species recovered. Estimated sandeel consumption was highest in Winter and lowest in Spring and Summer.

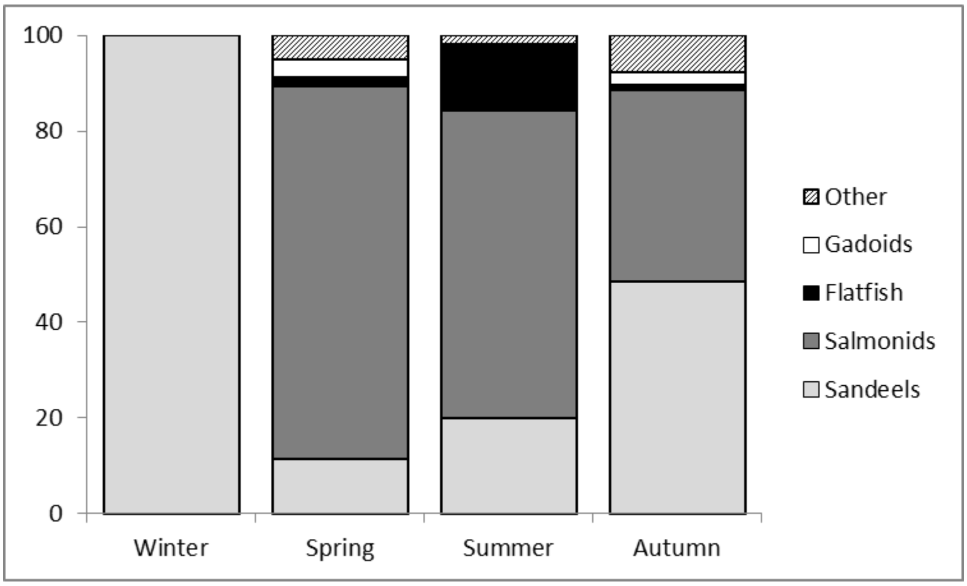


Figure 25.Average seasonal percentage by weight of each prey type in the diet of harbour seals in the Firth of Tay (reproduced using data presented in Sharples et al. 2009).

The size of fish consumed by harbour seals

The mean length of sandeel recovered increased from 12.6cm before 2000 (the year of the sandeel fishery closure) to 13.3cm after 2000. The difference in the distributions of the length of sandeel consumed by harbour seals before and after the sandeel fishery closure was highly significant (Kolmogorov-Smirnov, $D = 0.104$, $p < 0.001$; Sharples et al. 2009).

CONCLUSIONS

- The Forth and Tay area is important for both harbour and grey seals.

- Grey seals occur here in relatively large numbers - pup production here represents approximately 10-12% of pup production of the national population. The harbour seal population in the area is much smaller and represents approximately 2% of the national population.

- Grey seal numbers in the area are generally increasing whereas harbour seal numbers are decreasing.

- There are hotspots representative of important offshore foraging sites across several of the proposed WF sites. These illustrate a general preference for shallow, sandy areas. The importance of areas between these 'hotspots' and coastal haul out sites which seals must transit through must also be emphasised. The implications of displacement from these areas during windfarm construction must be carefully considered.

- There have been changes in the diet of grey seals in the region over the last three decades, with increasing reliance on sandeels and a general trend towards the consumption of smaller prey. Sandeels were also the dominant prey species found in the diet of harbour seals in the region. Pelagic species such as herring are relatively unimportant.

- Seasonal variation in species composition was evident in the diet of both seal species. Within-region spatial variation was evident in the diet of harbour seals; salmonids were the dominant prey type in the Tay in Spring and Summer while diet in St Andrews Bay was dominated by sandeels in all seasons.

- There are several issues which have the potential to complicate any assessment of impacts in this region. Of particular difficulty are the following:

    - The locally declining harbour seal population – the PBR (maximum total allowable 'take') for harbour seals in the East coast management unit encompassing this area is just 3 individuals (from Fraserburgh to the English Border). This may suggest that any further disturbance or displacement may be unacceptable for this population.

    - There is difficulty in a) predicting individual level effects of piling noise on seals because of a severe lack of empirical data on the physical and behavioural effects of impulsive noise on seals. This makes b) predicting the consequences for the individual of any impact difficult (in terms of foraging success and ultimately reproductive success and survival) and then, given these difficulties c) linking predicted individual level impacts to population level consequences. At every step in this process there are large uncertainties and it will be necessary to make assumptions and extrapolations. Any assessment will need to make these assumptions and extrapolations clear and predictions must be interpreted in light of the uncertainties inherent in the process.

- Modelling population consequences of impacts on individuals is particularly difficult for this local harbour seal population because the reason for the current decline is unknown. How individual impacts translate to effects at the population level will likely differ depending on whether the decline is a result of changes in adult survival, reduced fecundity, or reduced juvenile survival. Any population modelling depends on knowledge of these parameters (vital rates) and the outputs of any model will be sensitive to changes in these so unless we know what these are for a population we can't confidently model a population response to an impact. Extrapolating these vital rates from other populations may be inappropriate and result in erroneous conclusions.

- The grey seals in the region are very wide ranging and don't represent a single discrete, local population which makes assessing the consequences of impacts on these populations difficult. Tagged grey seals in this area overlap with a number of SACs and Habitats Regulation Assessments for these projects may need to consider impacts on a number of very widely located designated sites.

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GREY & HARBOUR SEAL USAGE MAPS FOR THE FORTH AND TAY OFFSHORE WIND DEVELOPERS FORUM (FTOWDG)

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METHODS

AVAILABLE DATA

AERIAL SURVEY

Aerial surveys are conducted each year by the Sea Mammal Research Unit (SMRU) and are funded by Scottish National Heritage (SNH) and the National Environmental Research Council (NERC). They are conducted from a helicopter throughout August and both grey and harbour seals are counted. At that time, harbour seals are found in moulting aggregations. Grey seals are in dispersed haul-outs along the coast. Over a number of consecutive years the entire Scottish coastline is surveyed and counts are marked using OS Landranger maps (1:50,000) to an accuracy of 50m. Data from 1996-2009 surveys were used in the analysis (Figure 1).

Fixed-wing aerial surveys for grey and harbour seals are also carried out during the August moult each year, funded by NERC and Natural England. These survey the Moray Firth, Tay estuary, and the Wash in East Anglia. Counts between 1988 and 2009 from the east coast of England were used in the analysis (Figure 1).

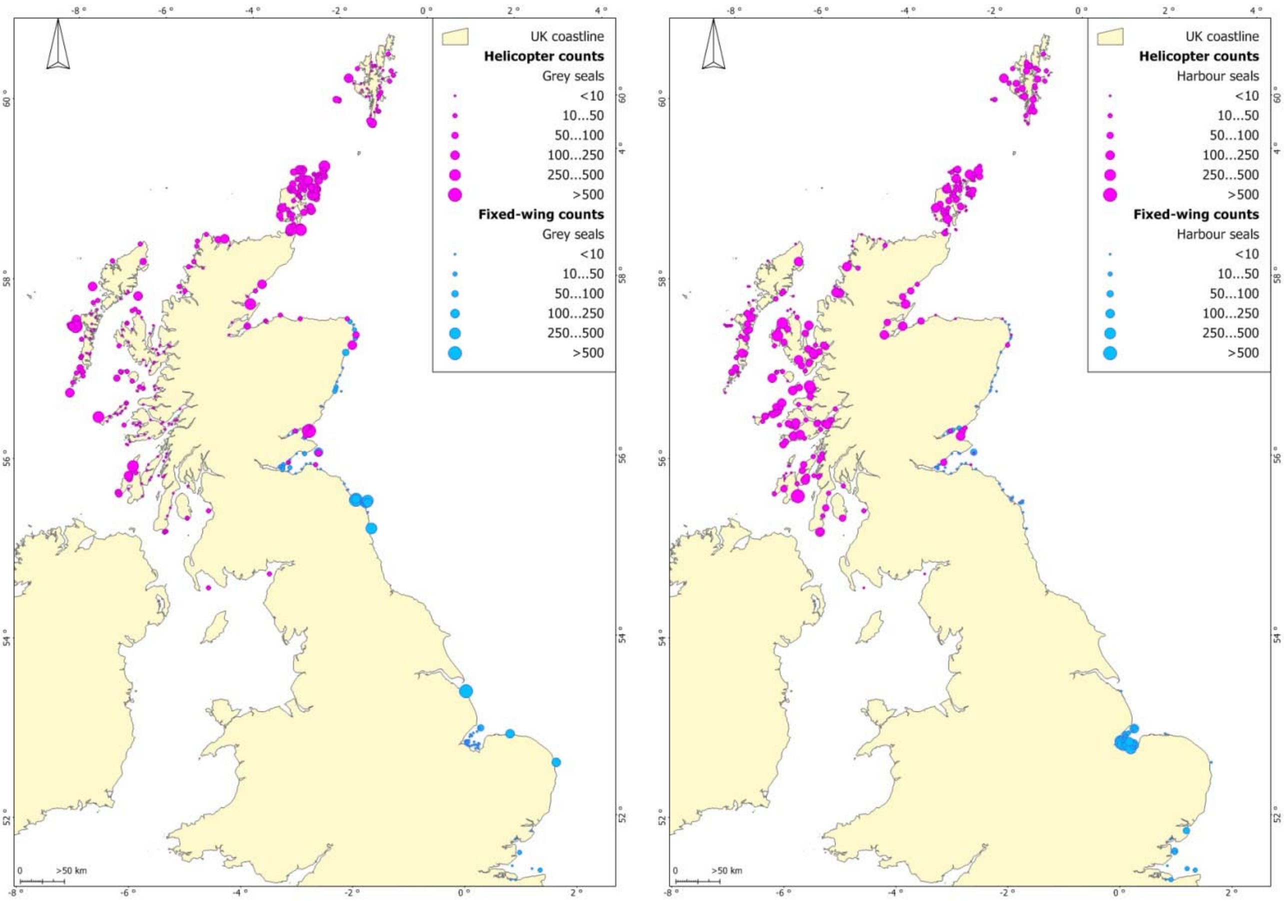

Figure 26. Aerial survey counts. (L) Grey seal counts using data from 1988-2009, (R) Harbour seal counts using data from 2006-09. See Aerial Survey Weighting for details of the non-linear weighted model used to produce a single count for each location by species.

TELEMETRY

Telemetry data from individual grey and harbour seals have been collected by SMRU since 1988. These comprise two sources: Satellite Relay Data Logger (SRDL) tags developed by SMRU use the Argos satellite system and were deployed between 1988 and 2010. GPS phone tags that use the GSM mobile phone network with a hybrid Fastloc protocol (McConnell *et al*., 2004) have been deployed since 2007.

Telemetry data were selected from the SMRU database by species and processed through a set of data cleansing protocols to remove null and missing values, duplicated records and ineligible data. Tracks were then selected based on the criteria that any part of a track passed within a 100km buffer zone of the FTOWDG proposed development sites, regardless of where tagging had taken place. 96 grey seal tracks were used in the final analysis (Table 1), tagged between 1991 and 2008 (mostly Argos tags). 67 of the tagged animals were adults, 3 were juveniles and 26 were moulted pups. The male to female ratio was 51:45.

Year	Tag type	Number of tags	Sex ratio (m:f)	Mean tag lifespan (days)	Mean number of location fixes (per day)
1991	Argos	5	4:1	107	2.7
1992	Argos	10	6:4	104	3.1
1993	Argos	3	2:1	95	1.9
1994	Argos	4	2:2	65	3.1
1996	Argos	8	1:7	48	1.7
1997	Argos	7	4:3	84	1.1
1998	Argos	12	8:4	186	0.8
2001	Argos	11	7:4	148	2.7
2002	Argos	11	5:6	111	3.1
2003	Argos	2	1:1	169	1.3
2004	Argos	1	0:1	130	10.2
2005	Argos	1	1:0	151	1.5
2006	Argos	2	1:1	69	6.7
2008	Argos/GPS	19 - (10 Arg, 9 GPS)	9:10	188	8.5
		Total=96	**51:45**	**Mean=131**	**Mean=4.1**

Table 11. Summary of grey seal telemetry tracks used in the final analysis.

25 harbour seal tracks were used in the final analysis (Table 2), tagged between 2001 and 2003 using Argos tags. All animals were adults and the male to female ratio was 13:12.

Year	Tag type	Number of tags	Sex ratio (m:f)	Mean tag lifespan (days)	Mean number of location fixes (per day)
2001	Argos	10	5:5	132	5.5
2002	Argos	5	4:1	138	4.9
2003	Argos	10	4:6	114	6.5
		Total=25	**13:12**	**Mean=126**	**Mean=5.7**

Table 12. Summary of harbour seal telemetry tracks used in the final analysis.

Figure 2 shows the geographical locations of grey seal tracks used in the analysis, split by tag type. Both GPS and Argos have similar spatial coverage, extending up to 700km away from the wind farms boundaries.

Figure 3 shows the grey seal tracks split by year from 1991-2008.

Figure 4 shows the spatial extent of the harbour seal Argos tracks from 2001-2003. Their range extends up to 250km away but is mostly concentrated to within 50km of the wind farms boundaries.

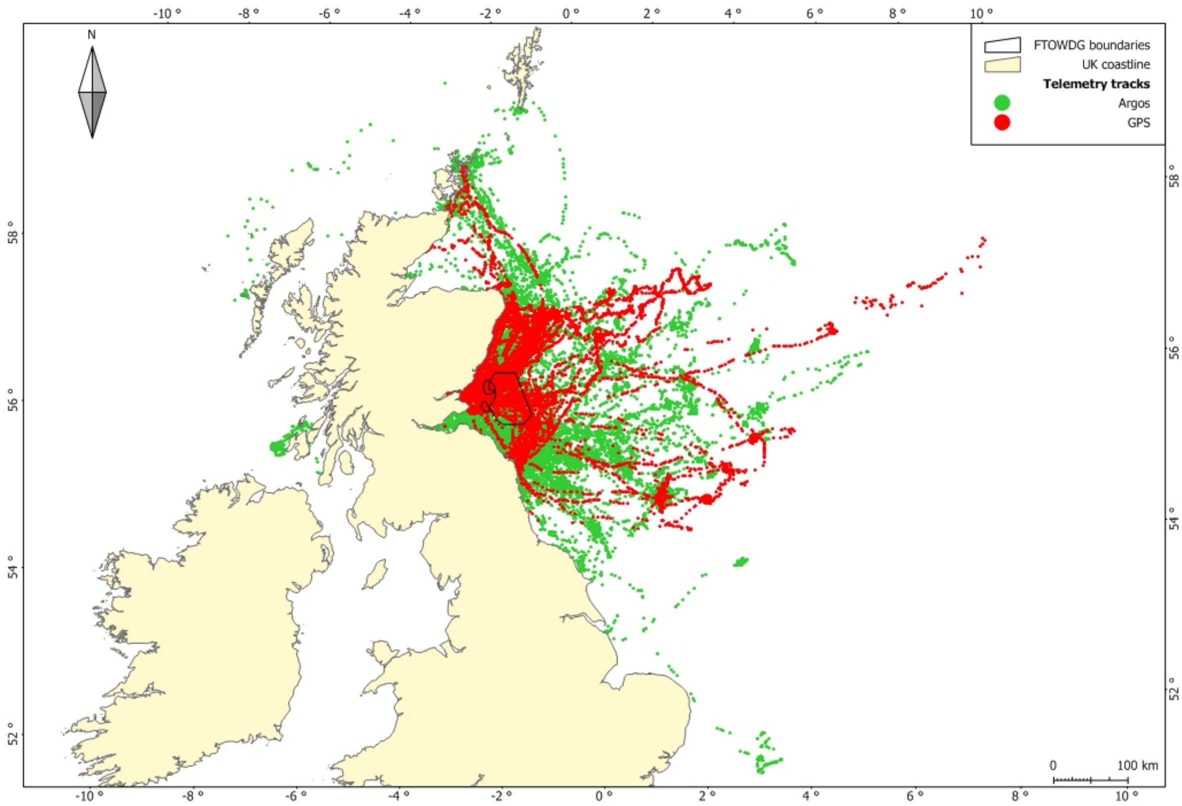

Figure 27. Grey seal telemetry locations by tag type.

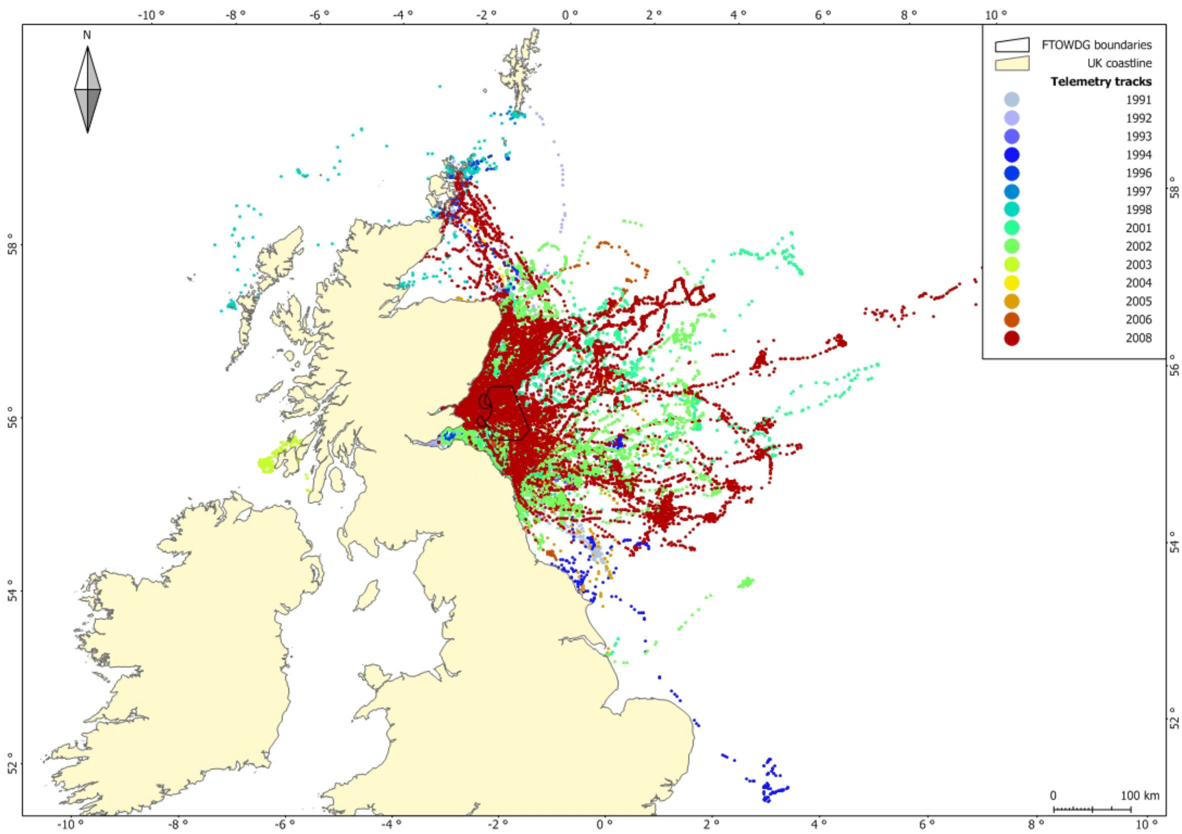

Figure 3. Grey seal telemetry track locations by year.

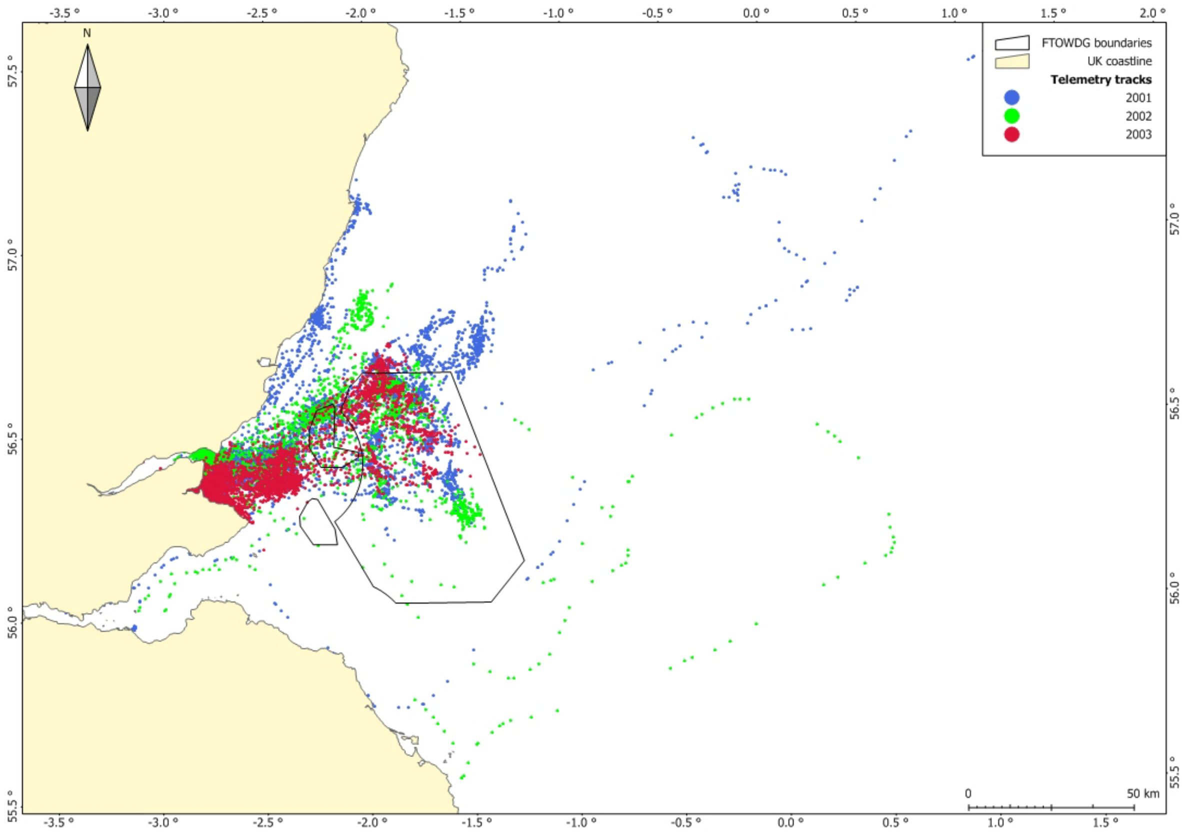

Figure 4. Map showing harbour seal telemetry locations by year.

UK COASTLINE

GSHHS 2.2.0 fine (f) resolution L1 data (Wessel & Smith, 1996) available to download from NOAA was used as the UK coastline layer in the usage maps.

SOFTWARE

The statistical package R (R Development Core Team, 2011) was used for data processing and analysis. GIS software Manifold version 8.0 was used to produce the maps. All maps are in Universal projection Transverse Mercator zone 30^{0} North (UTM30N), datum World Geodetic System 1984 (WGS84).

SPATIAL EXTENT

Data were gridded into 5km squares throughout the analysis. The spatial range incorporated all of a telemetry track if one or more locations in that track were located within 100km of the boundaries of the Firth of Forth, Neart na Gaoithe, or Inch Cape proposed offshore wind farm developments.

TREATMENT OF POSITIONAL ERROR

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

There are many approaches to addressing the problem ranging from simple moving average smoothers to elaborate state-space models, but none have offered a comprehensive solution combining automation, computational speed, precision and accuracy. Since we are interested in large-scale population-level inferences rather than high-resolution individual-based insights we opted for a Kalman filter (Royer & Lutcavage, 2008; Patterson *et al.*, 2010; Roweis & Ghahramani, 1999) using a linear Gaussian state space model to obtain estimates, accounting for observation error. This has been developed in-house to give flexibility and fast processing times. Argos data were first speed-filtered (McConnell *et al.*, 1992) at $2 ms^{-1}$ to eliminate locations that would require an unrealistic travel speed between locations (Russell *et al.*, 2011). Observation model parameters were provided by the location class errors described above, and process model parameters were derived from Vincent *et al.* (2002).

GPS tags are generally more accurate than Argos tags, and 95% of these data have a distance error of less than 50m. However, occasional errors do arise and these data were excluded from the analysis by removing data with residuals that were either 0 or greater than 25, and removing locations with less than 5 satellite fixes (Russell *et al.*, 2011).

HAUL-OUT DETECTION

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

HAUL-OUT AGGREGATION

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

KERNEL SMOOTHING

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

HAUL-OUT DENSITY

Hauled-out usage was calculated by multiplying the proportion of telemetry points at each haul-out site by the estimated kernel smoothed at-sea density.

AERIAL SURVEY WEIGHTING

Aerial survey counts were used to scale up the telemetry data. The helicopter and fixed-wing counts were de-duplicated to ensure each 5km grid only had either helicopter or fixed wing counts associated with it. Aerial survey data were weighted using a power-law which assigned increasing importance to more recent data, to produce a single count for each 5km grid where animals had been counted. For grey seals all available years were included. For harbour seals, data from 2005-2009 were used due to the recent east coast population decline (Lonergan et al, 2007), to more accurately represent current abundance estimates.

$$Grey\ seal\ weighted\ count = \frac{\sum_{2009}^{1988} \left(0.8_{year}^{2009-year} \times count\right)}{\sum_{2009}^{1988} 0.8^{2009-year}}$$

$$Harbour\ seal\ weighted\ count = \frac{\sum_{2009}^{2005} \left(0.8_{year}^{2009-year} \times count\right)}{\sum_{2009}^{2005} 0.8^{2009-year}}$$

INFORMATION CONTENT WEIGHTING

To account for individual variation in the telemetry points collected from each animal, indexes of information content were devised for the 99 remaining grey seals and 25 remaining harbour seals (see Appendix – Data waterfall). For each species models were built separately for total and at-sea usage. The response variable was rate of discovery, defined by the number of new 5km grid cells an animal 'discovers' in the lifespan of the telemetry tag. This rate was modelled as a function of the number of received telemetry locations for an animal, tag lifespan and whether the tag was Argos or GPS (for grey seals only). The intercept was set to zero and a Poisson distribution with a log link function was used.

The grey seal models used Generalised Additive Models (GAMs) utilising the R library MGCV (Wood S, 2011; Wood, 2006). Figure 5a shows a boxplot of grey seals tag type vs. discovery rate for total usage (at-sea data produced very similar results and is therefore not shown). The mean number of grid cells discovered throughout a tag's lifespan are shown by red triangles (Argos = 150, GPS = 316). A Welch two-sample t-test gave a significant difference between the means at a 90% confidence level. This was driven by a significantly higher tag lifespan (Figure 5b; Argos = 2884 hours, GPS = 4345 hours), and higher uplink rate per hour (Figure 5c; Argos = 0.20, GPS = 0.56).

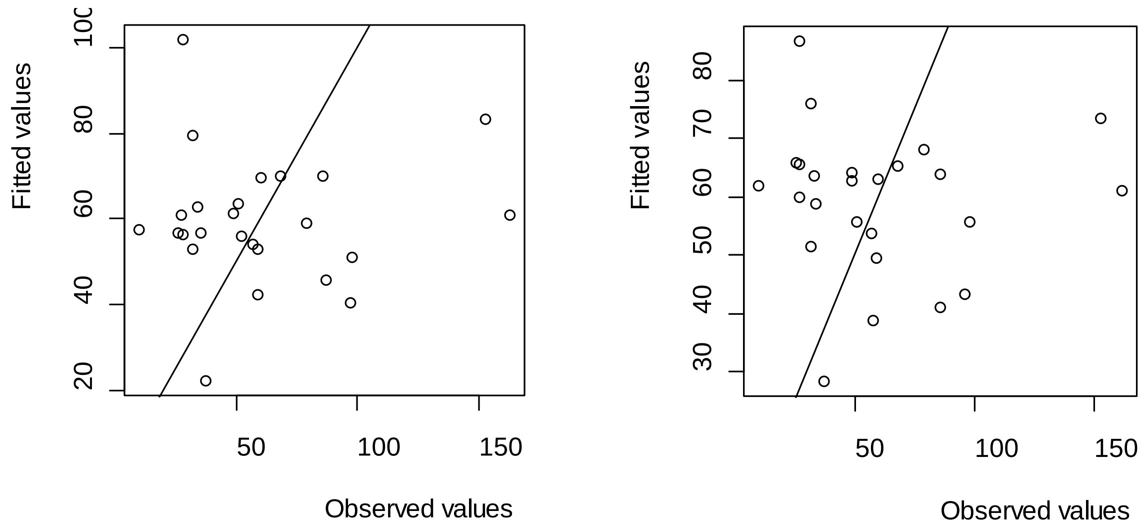

Figure 7. GLM models deriving 'information content' by individual harbour seal. Observed vs. fitted values for: 7a. Total usage; 7b. At-sea usage.

Fitted values were normalised and used to weight the contribution of different animals to estimated usage associated with each haul-out location. This approach reduced the importance of data-poor animals, whilst simultaneously not overstating the contribution of animals with heavily auto-correlated observations.

POPULATION SCALING

Grey seals haul-out for approximately 35% of their time (with 95% confidence intervals between 32% and 38%) during the summer irrespective of sex, length (as a proxy to age), region (i.e. location), or survey timing (Lonergan *et al.*, 2010). Therefore, to scale the weighted aerial survey counts up to a population estimate, a scalar multiplier of 2.85 (100/35.05) was applied.

Harbour seals haul-out for approximately 72% of their time (with 95% confidence intervals between 54% and 88%) during the moult in August (Lonergan *et al.*, in press), based on studies from animals in Orkney and western Scotland. Therefore, harbour seal counts are scaled to a population level using a scalar multiplier of 1.39 (100/72).

NULL (ACCESSIBILITY) MODEL

To account for areas in the maps where aerial survey data were present but telemetry data were not, null maps of estimated density were produced for each species. GLMs were used to model the number of telemetry locations associated with each haul-out. This count was modelled using at-sea distance from the haul-out to represent accessibility by animals to each haul-out, and the distance to the shore to represent accessibility to the coast. All 25 harbour seals tracks were used and a random sub-sample of 25 grey seal tracks were selected. A Poisson distribution with a log link function was used. Figure 8 shows the observed vs. fitted number of telemetry locations associated with each haul-out for (a) grey seals and (b) harbour seals.

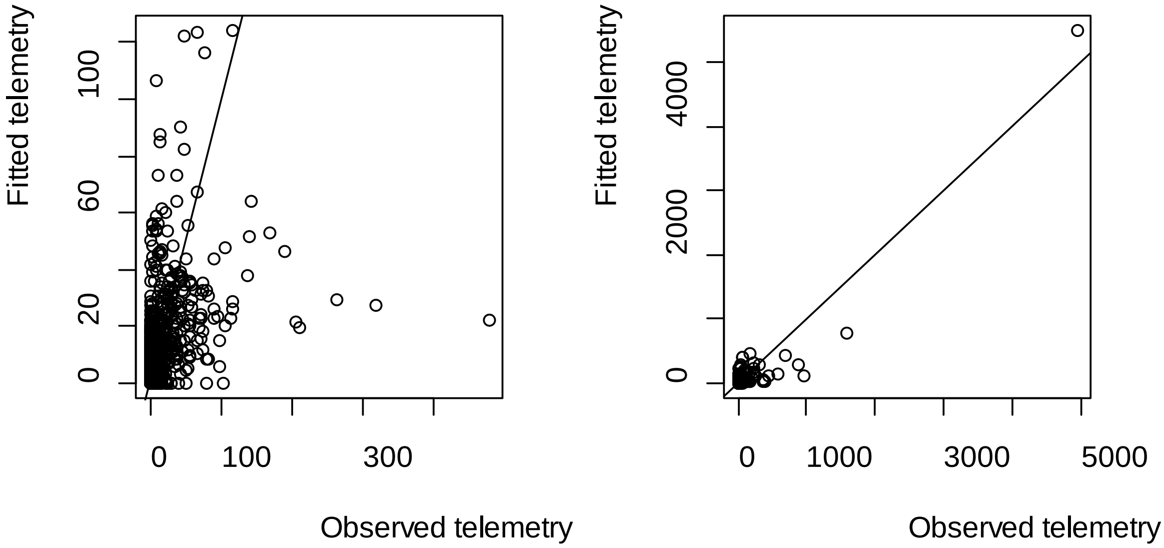

Figure 8. GLM models deriving null usage. Observed number of telemetry locations vs. fitted locations for: 8a. Grey seals; 8b. Harbour seals.

CONFIDENCE INTERVALS

Uncertainty within haul-outs was propagated through the analysis using two sources: by estimating the variability in the telemetry data and using variability in the null usage models.

TELEMETRY DATA VARIANCE

For each species, Linear Models (LMs) were built to estimate variance. All haul-outs with more than 5 (for harbour seals) or 6 (for grey seals) animals associated with them were used. The response variable was logged variance and covariates were sample size (number of animals associated with a haul-out) and logged estimated mean density of seals weighted by information content. At-sea kernel smoothed densities were bootstrapped 500 times for each haul-out, and sample size was sampled with replacement and logged, to produce estimated logged variance and logged mean densities. The grey seal model used both covariates with an interaction term; the harbour seal used both covariates without an interaction term.

NULL USAGE VARIANCE

Estimated mean densities in the null maps were produced using a Poisson log link distribution. Therefore, the variance in these maps was equal to the mean.

According to the central limit theorem, the aggregated variance maps were normally distributed and so were scaled up to confidence intervals using a scalar multiplier of 1.96.

ANALYSIS

To create maps of total, at-sea, and hauled-out usage, all grey and harbour seal telemetry data from the SMRU database were put through a series of data cleansing protocols to remove unusable data (Appendix 1 – data waterfall). Argos data were spatially interpolated using a Kalman filter and merged with GPS data. Any part of a track that had at least one location within a 100km buffer zone of the FTOWDG proposed development sites, was selected for the analysis regardless of where tagging had taken place.

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

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

For total usage, each animal/haul-out map was multiplied by a normalised Information Content Weighting to correct for individual animal bias. All maps connected to each haul-out were aggregated and hauled-out density was added onto each map. Each map was then scaled to the estimated number of animals using that haul-out using the weighted aerial survey counts and then further scaled to the population estimate. A null usage map was derived for each aerial survey site without corresponding telemetry data. Each map was normalised, scaled to aerial survey counts and population estimates, and added to the total usage map.

For at-sea usage, each animal/haul-out map was multiplied by the normalised at-sea Information Content Weighting. Each map was normalised and multiplied by the proportion of telemetry locations not hauled-out. All maps connected to each haul-out were aggregated and scaled to weighted aerial survey counts and then population estimate. Null usage maps were derived using the same process as total usage, but were multiplied by the total proportion of time animals spent not hauled-out (see Population Scaling above) before being added to the at-sea usage map.

Variance in the telemetry data were then estimated for each species (grey and harbour)/usage (total and at-sea) combination. For total usage, the uncertainty models predicted variance by grid cell for the animals associated with each haul-out, which were then aggregated over all haul-outs. The models were applied in the same way to at-sea usage and both sets of variance maps were scaled to aerial survey counts and population estimates. For the null usage maps, variance was equal to estimated density. Each grid cell was normalised and scaled appropriately to population estimates for total and at-sea usage and added to the telemetry data variance maps. The maps were then scaled up to confidence intervals.

Hauled-out usage and variance was calculated by subtracting the at-sea usage and variance from the total usage and variance, for each species.

USAGE MAPS

GREY SEALS

Figure 9 shows total estimated spatial usage of grey seals around the FTOWDG proposed development sites. The map can be interpreted as the average number of seals in each 5km^2 grid square at any point in time. For example, a green square denotes, on average, between 1 and 5 grey seals will be within that grid square at any point in time. A red square denotes over 50 animals will be in a grid square at any point in time.

White contour lines denote standard deviation from the mean as a measure of uncertainty around the estimated usage. Labels show the value of standard deviation at each contour as the square root of the estimated variance. This in turn was a combination of two modelling processes: null usage and telemetry data. Variance from the null model was larger than for estimates informed by telemetry data. Therefore, in regions that received considerable usage from haul-outs for which no telemetry data were available, uncertainty contours may appear smoother than for regions rich in telemetry data. This is a desirable feature of the model: it inflates uncertainty in regions where the ratio of data to usage is likely to be low.

Within the study area, the largest aggregations of high usage are located at the mouth of the Firth of Tay and near Berwick-upon-Tweed. Possible offshore foraging patches can also be seen throughout the region, with an aggregation of high usage on the northern boundary of the Firth of Forth proposed wind farm development.

Figure 10 shows estimated grey seal at-sea usage with white contour lines denoting standard deviation. Total and at-sea usage display similar characteristics, although at-sea usage is 20% lower due to the removal of hauled-out usage.

Figure 11 shows estimated grey seal hauled-out usage with white contour lines denoting standard deviation. The largest aggregations of high usage occur in the Firth of Forth, Firth of Tay and near Berwick-upon-Tweed.

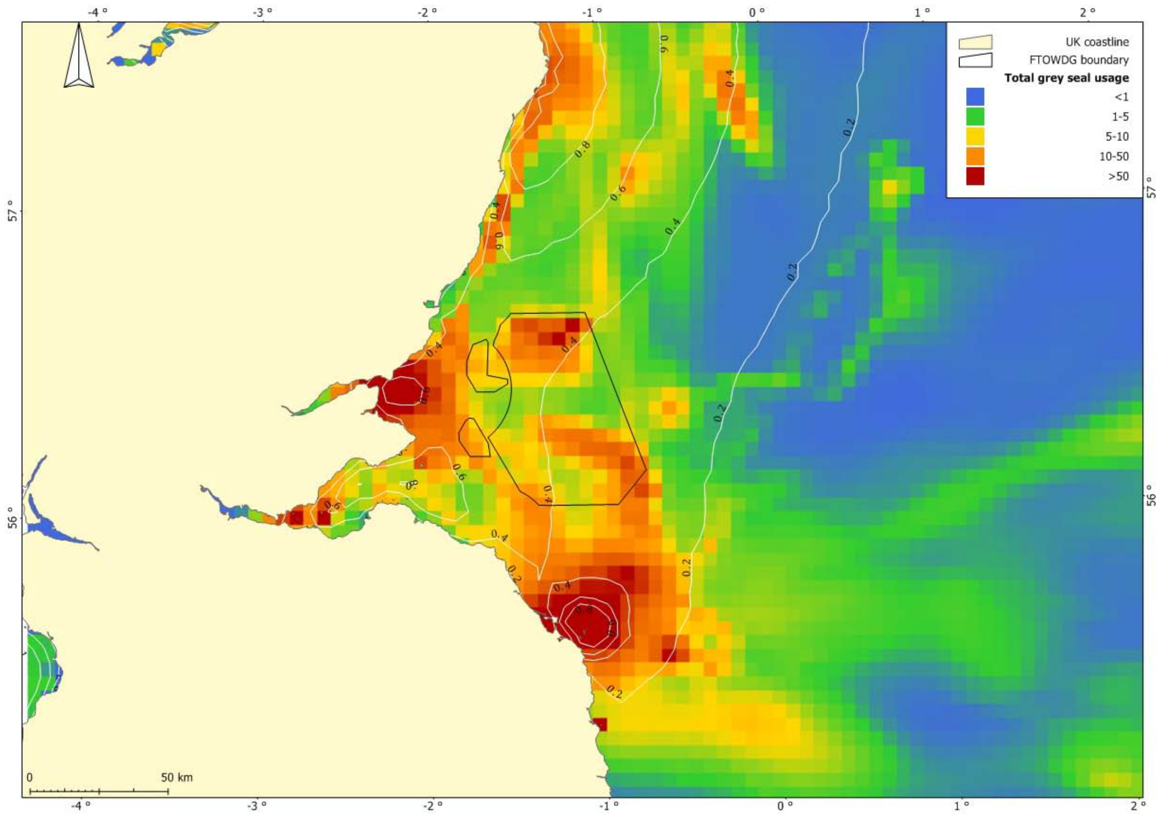

Figure 9. Estimated grey seal total (at-sea & haul-out) usage around the FTOWDG proposed development sites. White contours show standard deviation from mean usage as a measure of uncertainty.

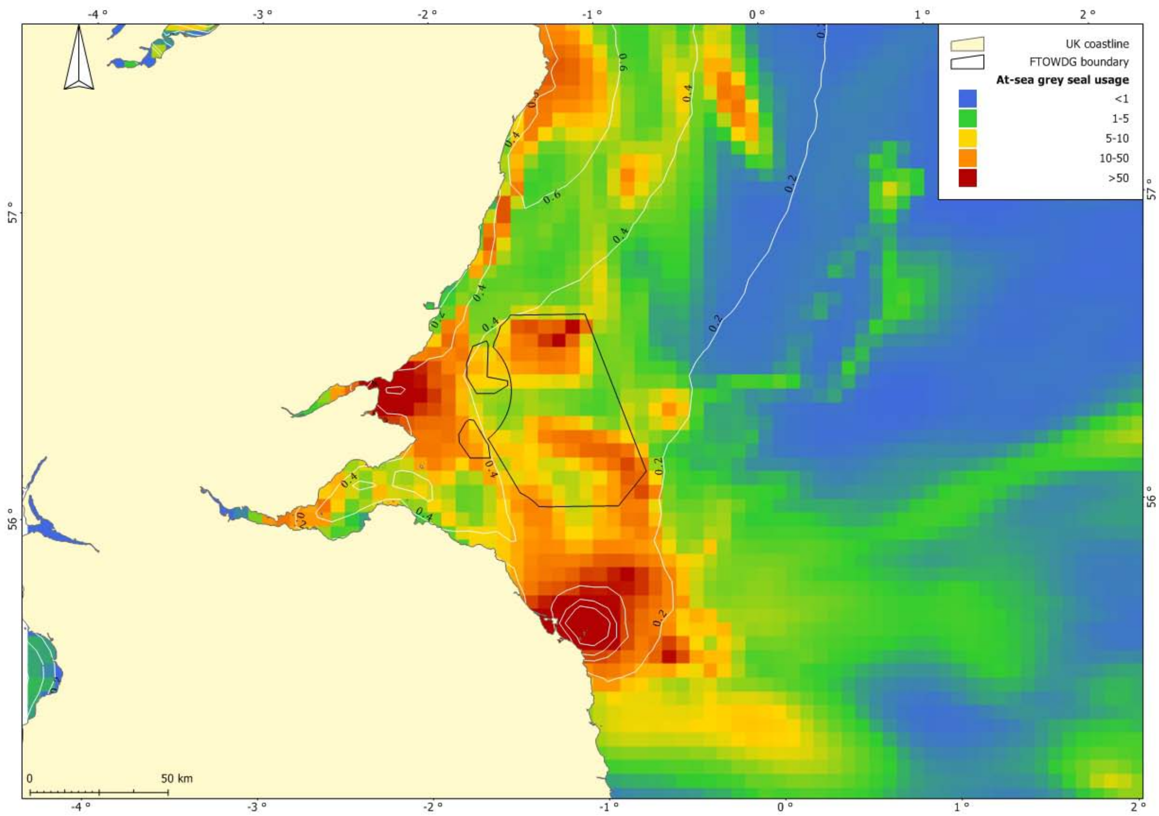

Figure 10. Estimated grey seal at-sea usage around the FTOWDG proposed development sites. White contours show standard deviation from mean usage as a measure of uncertainty.

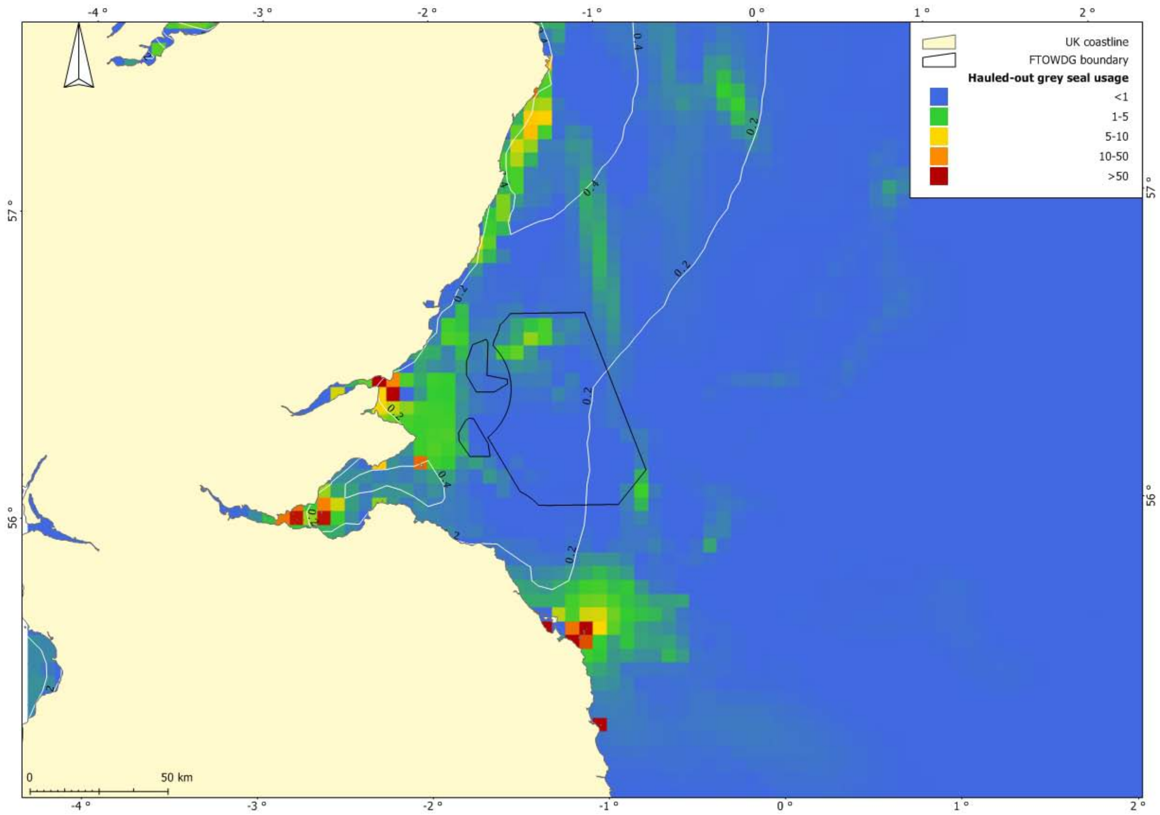

Figure 11. Estimated grey seal hauled-out usage around the FTOWDG proposed development sites. White contours show standard deviation from mean usage as a measure of uncertainty.

HARBOUR SEALS

Figure 12 shows estimated total spatial usage of harbour seals around the FTOWDG proposed development sites with standard deviation denoted by white contour lines. Usage extends out from an area of haul-out sites located at the mouth of the Firth of Tay to possible offshore foraging sites.

Figure 13 shows estimated harbour seal at-sea usage that displays similar characteristics to total usage. Standard deviation is denoted by white contour lines.

Figure 14 shows estimated harbour seal hauled-out usage with standard deviation denoted by white contour lines. Hauled-out usage is concentrated at the mouth of the Firth of Tay. Higher uncertainty is associated with these haul-outs.

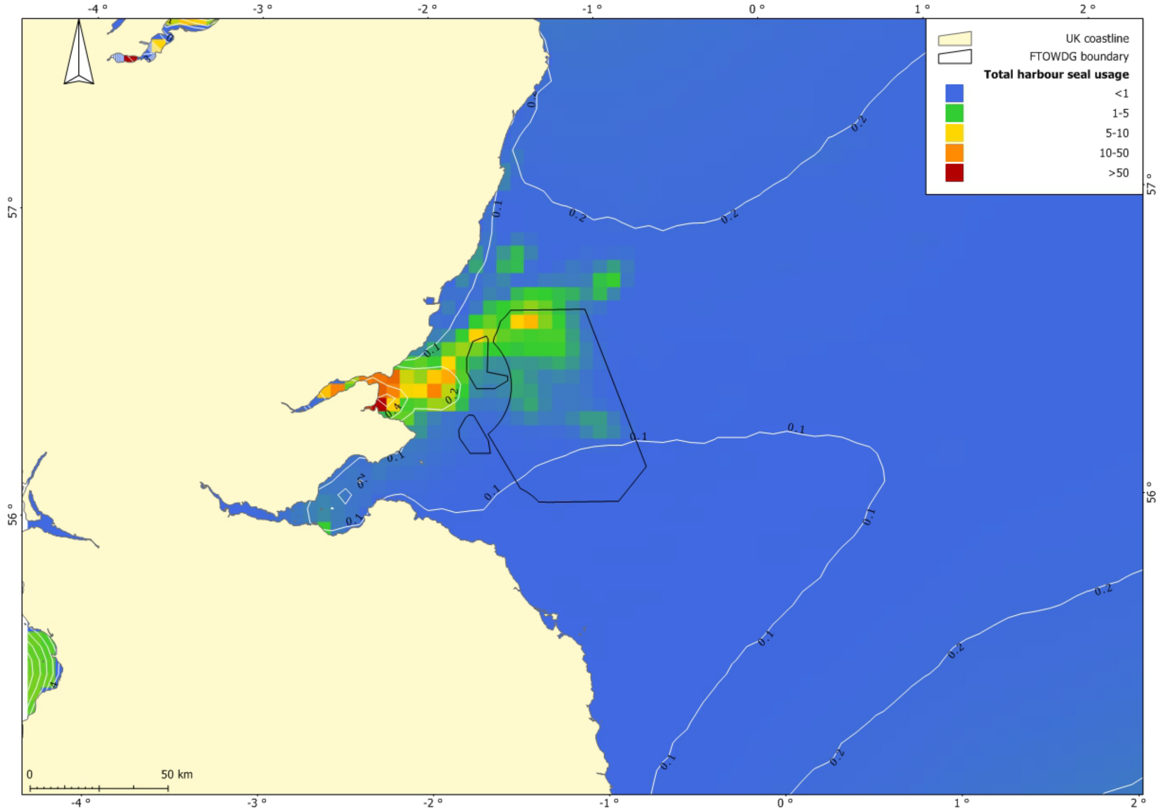

Figure 12. Estimated harbour seal total (at-sea & hauled-out) usage around the FTOWDG proposed development sites. White contours show standard deviation from mean usage as a measure of uncertainty.

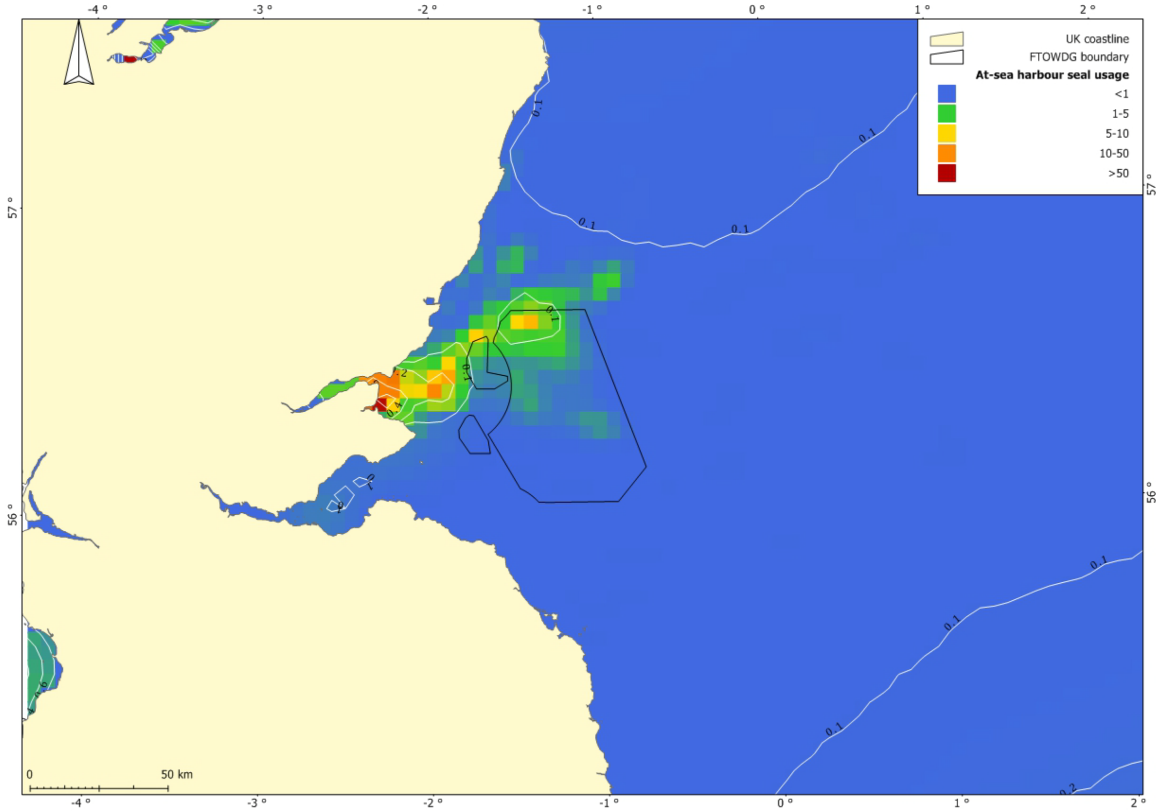

Figure 13. Estimated harbour seal at-sea usage around the FTOWDG proposed development sites. White contours show standard deviation from mean usage as a measure of uncertainty.

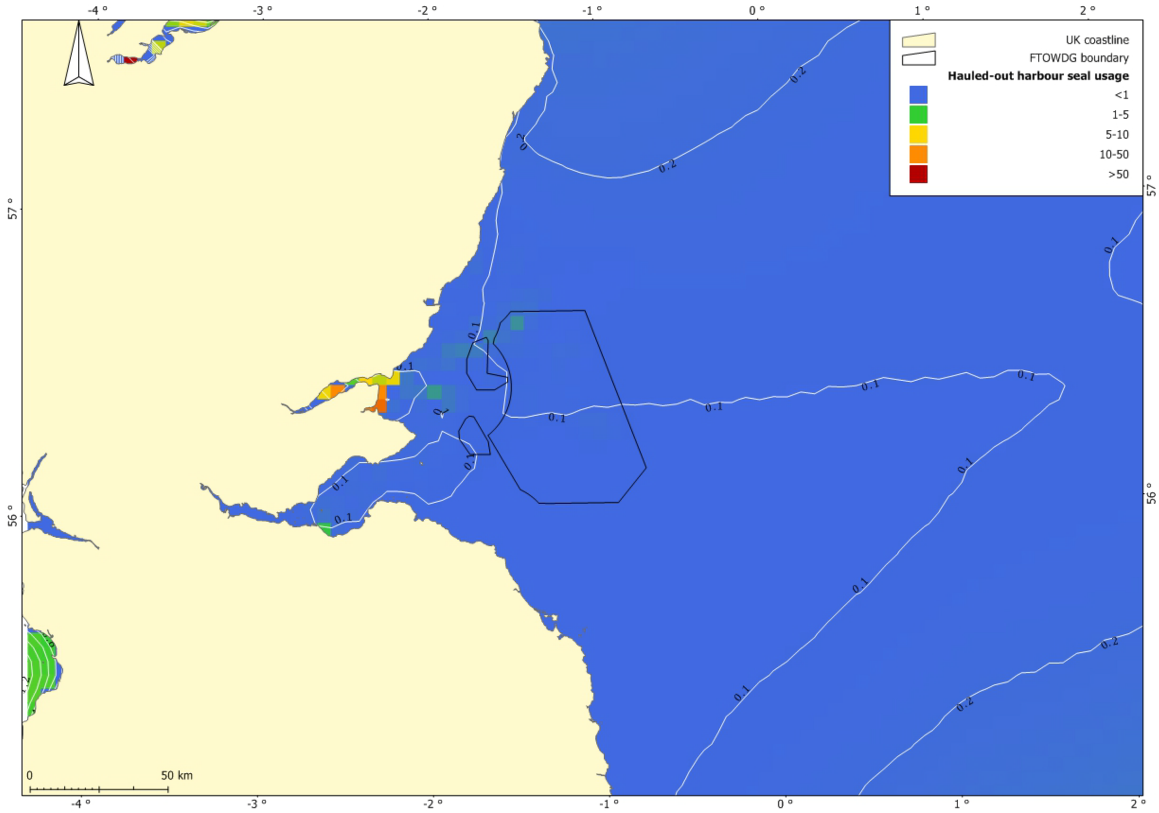

Figure 14. Harbour seal hauled-out usage around the FTOWDG proposed development sites. White contours show standard deviation from mean usage as a measure of uncertainty.

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