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Grey seal diet composition and prey consumption

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1 Executive Summary

Since the last comprehensive assessment of grey seal diet around Britain in 2002, grey seal numbers have continued to rise in the North Sea while harbour seal numbers have declined in Shetland, Orkney and southeast Scotland. Stocks of gadid fish have also declined. In this report on task CSD3.3 of the MMSS/001/11 programme, grey seal diet is reassessed in 2010/11 and compared to previous assessments in 1985 and 2002, and estimates of prey consumed by grey seals are compared with fish stock sizes to estimate percent predation mortality.

Grey seal scats were collected seasonally throughout Scotland and along the east coast of England over a 12 month period in 2010/11. Methods used to estimate diet followed those used in previous years. Hard remains of prey (fish otoliths and cephalopod beaks) were recovered, identified and measured, and corrections made to account for partial and complete digestion. Diet composition was estimated as the percentage, by weight, of each species in the diet for each region and season. Prey consumption was estimated assuming that grey seal populations met their annual energy requirements. Sampling variability was estimated using non-parametric and parametric bootstrap resampling methods.

A total of 2,205 grey seal scats containing hard prey remains were processed, yielding 68,465 otoliths and beaks. In the Western Isles, estimated diet was dominated by sandeel and gadid prey, particularly cod and ling. In the Northern Isles, the diet was also dominated by sandeel and gadid prey, particularly saithe and cod. Sandeel made up around a quarter of the diet in Shetland and around half of the diet in Orkney. In the central North Sea, diet was heavily dominated by sandeel but was more varied in the southern North Sea.

Overall, grey seals were estimated to have consumed 129,200 t (95% conf. interval: 114,800-149,400 t) of prey in the North Sea (ICES Subarea IV) and 70,300 t (95% conf. interval: 60,000-84,000 t) of prey west of Scotland (ICES Division VIa) in the 12 months from April 2010 to March 2011; a grand total of 199,500 t (95% conf. interval: 181,200-225,500 t).

Diet composition appears to have changed little in the Western Isles from 1985 to 2002 to 2010/11. In the Northern Isles, changes in diet composition were characterised by a marked decline in the contribution of sandeel in Shetland and a more gradual decline in Orkney, and an increase in the contribution of gadids. In the central North Sea, however, the change in the contribution of sandeel and gadids was the reverse of that seen in the Northern Isles. Gadids declined markedly but sandeel increased steadily between 1985 and 2010/11.

In the North Sea (ICES Subarea IV), consumption by seals as a percentage of estimated stock size is estimated to be small; the highest figure is for cod (5% in 2010). West of Scotland (ICES Division VIa), however, estimated consumption by seals as a percentage of estimated stock size is larger for whiting (10% in 2010) and very large for cod (> 100% in 2010). These figures increase to ~50% and > 200%, respectively, if harbour seal consumption is also included. The partial coverage of west coast cod by the stock

assessment and the lack of overlap between the area of the fishery and the area where seals forage provide an explanation for how the estimated consumption by seals can be so large relative to the size of the assessed stock.

2 Introduction

The grey seal (*Halichoerus grypus*) is a major marine predator around Britain, especially in Scottish waters, and has long been viewed as a competitor to commercial fisheries, particularly for cod (Harwood and Croxall 1988). Information needed for assessing the impact of grey seals on fisheries (and *vice versa*) includes which species of fish are taken and how much fish is consumed. Direct observation of seal diet is not possible but a robust method for assessment of grey seal diet around Britain is the analysis of hard prey remains recovered from scats collected at haul-out sites (Prime and Hammond 1987).

Grey seal diet was previously comprehensively assessed around Britain in 1985 (Prime and Hammond 1990, Hammond *et al.* 1994a, b) and 2002 (Hammond and Grellier 2006, Hammond and Harris 2006). Between these dates, there were declines in the stocks of most commercially exploited fish species and the grey seal population increased by 35% off western Scotland and by 235% in the North Sea, including Orkney (ICES 2014; Thomas 2014). Estimated grey seal consumption relative to estimated stock size from ICES stock assessments, therefore, generally increased from 1985 to 2002 but remained relatively low for most stocks (Hammond and Grellier 2006; Hammond and Harris 2006). Predation by grey seals relative to estimated stock size was greatest for cod in 1985 and 2002, in both ICES Subarea IV (North Sea) and Division VIa (west of Scotland).

Since 2002, stocks of gadids (cod, haddock, whiting, saithe) have declined further, as has herring west of Scotland (ICES, 2014). The grey seal population has continued to increase in the North Sea but remained stable in the Inner and Outer Hebrides (Thomas 2014). New information on grey seal diet composition and prey consumption is needed to obtain up to date information on predation mortality on commercially important fish stocks.

During this period (since around 2000), harbour seal (*Phoca vitulina*) numbers have declined in Orkney, Shetland and along the east coast of Scotland, while remaining more or less stable or increasing west of Scotland and in the southern North Sea) (Lonergan *et al.* 2007; Duck *et al.* 2015). One of a number of possible contributing causes for these declines is competition for prey resources with grey seals (Sea Mammal Research Unit 2012, 2014). Up to date information on grey seal diet is, therefore, important to investigations into whether or not grey seals may be contributing to harbour seal declines.

In this report on task CSD3 of the MMSS/001/11 programme, work to address the following objectives is described:

- Estimate grey seal diet composition in 2010/11, regionally and seasonally;
- Assess how diet around Britain in 2010/11 has changed compared to 1985 and 2002;
- Estimate grey seal prey consumption in 2010/11, regionally;
- Assess how consumption by seals as a percentage of estimated stock size of commercially important fish stocks in the North Sea (ICES Subarea IV) and west of Scotland (ICES Division VIa) has changed in 2010/11 compared to 1985 and 2002.

3 Methods

Diet composition and prey consumption were estimated using scat sampling methods as previously used in 1985 and 2002 and as described in detail in previous reports to Defra and Scottish Government (Hammond and Grellier 2006, Hammond and Harris 2006). Scats were collected on a quarterly basis for one year in 2010/11 around Scotland and along the east coast of England. Fish otoliths and cephalopod beaks recovered from scats were identified and measured, corrected for partial and complete digestion using experimentally derived coefficients, and the data used to estimate the contribution of each prey species to the diet as a proportion of the total estimated weight consumed.

Diet composition was estimated regionally (Inner Hebrides, Outer Hebrides, Shetland, Orkney and northern North Sea, central North Sea and southern North Sea) and seasonally. Diet composition results were used to estimate the amount consumed of each prey species, assuming that grey seals, on average, met their estimated energy requirements. Annual consumption estimates were compared with the estimated size of stocks assessed by ICES in Subarea IV (North Sea) and Division VIa (west of Scotland). Results for 2010/11 were compared with those previously presented for 1985 and 2002.

3.1 Sample Collection

Grey seal scats were collected seasonally for one year (quarters 2, 3 and 4 in 2010, and quarter 1 in 2011) at all major haul-out sites in Scotland and the east coast of England, as far as possible. Scat collection trips targeting grey seals were made in December 2010 (post-pupping) and February 2011 (moulting period). All other grey seal scats were collected during sampling trips focussed primarily on harbour seals. Table 1 lists the sampling sites.

Fresh scat samples produced by individual grey seals were collected in separate plastic bags and stored at -20°C.

3.2 Sample Processing

Sample processing in the laboratory generally followed the procedure used in processing of 2002 samples, as described in Hammond and Grellier (2006) and Hammond and Harris (2006), as summarised below.

In 1985 and 2002, hard prey remains (fish otoliths and cephalopod beaks) were extracted from defrosted scat samples using a nest of sieves of decreasing mesh size. For 2010/11, individual scats were defrosted, placed in nested mesh bags (inner 350 µm, outer 240 µm) and soaked in warm water with 25 g detergent (Dreft) for 2-24 h. They were subsequently machine washed (Orr *et al*., 2004) following the protocol developed by Brasseur (pers. comm.), which involved a 2 h 40°C pre-wash with 50 g detergent and 0.5 h wool wash at 40°C with 50 g detergent; the spin cycle was deactivated for all wash cycles. If pebbles had been picked up as part of the individual scat collection then otoliths and beaks were extracted using running water through a nest of sieves, mesh sizes 1 mm, 600 µm, 335 µm and 250 µm, to avoid damage to prey hard remains. The presence of other possible prey remains (e.g. feathers and crustacean carapaces) was noted.

Fish otoliths and cephalopod beaks recovered from scats were identified to species by John Watkins (otoliths) and Caya Sievers (beaks). Otoliths and beaks that could not be identified to species level were assigned to more general categories; e.g. unidentified gadid and unidentified flatfish. In particular, as in previous studies of grey seal diet around Britain, sandeel otoliths could rarely be identified to species and were categorised simply as sandeel.

Otolith lengths and widths were measured to the nearest 0.01 mm using digital callipers (Mitutoyo) under a binocular microscope. The callipers were zeroed between measurements and were frequently cleaned. Otoliths and beaks were counted and measured only if the widest/longest part of the otolith, or the lower beak, was complete.

All counted otoliths and beaks were measured unless a large number of a prey species occurred in a scat. In such cases, 30 were randomly chosen and measured if there were 30-120 otoliths or beaks of the same species in a scat, and 25% were randomly chosen and measured if there were greater than 120 otoliths or beaks of the same species.

Each recovered otolith was examined to assess and record the amount by which it had been digested, based on its external morphological features (Tollit *et al.* 1997). Pristine (or nearly so) otoliths were classified as grade 1, moderately digested otoliths as grade 2 and considerably digested otoliths as grade 3, after Leopold *et al.* (2001). The amount by which cephalopod beaks had been digested was not classified.

Table 1: Sampling sites around Scotland and along the east coast of England.

Area	Sampling site(s)
Hebrides - North Inner	Glas Leac Beag, Summer Isles
Hebrides - North Inner	Glas Leac mor, Summer Isles
Hebrides - North Inner	Acairseid Mhor, Summer Isles
Hebrides - North Inner	Oldnay island group
Hebrides - Minch	Eilean Trodday
Hebrides - Minch	Shiants
Hebrides - Minch	Sgeir leathann, Broad bay
Hebrides - Minch	Crowlin islands
Hebrides - Minch	Ascrib islands
Hebrides - South Inner	Coll, Gunna, Tiree
Hebrides - South Inner	Oransay
Hebrides - South Inner	Nave Island
Hebrides - South Inner	Treshnish Isles
Hebrides - South Inner	Gigha, Caolas gigalum
Hebrides - North Outer	Loch Roag Isles
Hebrides - North Outer	Gaskier
Hebrides - North Outer	Sound of Harris
Hebrides - Monachs	Cean Iar
Hebrides - Monachs	Sibhinis
Hebrides - Monachs	Monach Islands
Hebrides - South Outer	Mingulay
Shetland	Lady's Holm/ Little Holm
Shetland	Out Skerries
Shetland	Mousa
Shetland	Yell Sound
Shetland	SE Shetland
Shetland	Vementry
Orkney	Sule skerry
Orkney	Pentland skerries
Orkney	Copinsay/ Cornholm
Orkney	Auskerry
Orkney	Sanday
Orkney	Holm of Papay
Orkney	North Ronaldsay
Orkney	Green Holms
Orkney	Faray/ Holm of Faray
Orkney	Switha
Orkney	Gaskier/ Sweyn Holm
Orkney	Barrel of Butter
Orkney	Eynhallow
Orkney	Westray
Orkney	Burgar
Moray Firth	Dornoch Firth
Moray Firth	Ardesier
Moray Firth	Beauly Firth
Moray Firth	Findhorn
South east Scotland	Abertay/ Eden Estuary
South east Scotland	Isle of May
South east Scotland	Dalgety Bay
South east Scotland	Ythan Estuary
North east England	Farne Islands
South east England	Donna Nook
South east England	Blakeney

3.3 Estimation of Diet Composition

All data processing and analysis was conducted using a suite of analysis programs written in software R (R Core Development Team 2013).

The methods used to estimate diet composition and amount of prey consumed by grey seals followed those used in previous analyses of seal diet by the Sea Mammal Research Unit (Prime and Hammond 1987; Prime and Hammond 1990; Hammond *et al.* 1994a, 1994b, Hammond and Rothery 1996, Hall *et al.* 1998, Hammond and Grellier 2006; Hammond and Harris 2006, Sharples *et al*. 2009). In particular, methods followed those used for the analysis of 2002, and reanalysis of 1985, grey seal diet data, as described in Hammond and Grellier (2006) and Hammond and Harris (2006), which are summarised below. For consistency, data from 1985 and 2002 were reanalysed with the new suite of analysis programs and updated data (see below).

Measurements of the size of fish otoliths and cephalopod beaks recovered from scats were corrected for partial digestion to estimate undigested otolith/beak size using grade-specific experimentally derived digestion coefficients (Grellier and Hammond 2006). For species for which no experimental data were available, either group-specific (e.g. gadids, flatfish) values or the values for the closest matching species were used. The digestion coefficients used were the same as previously used for analysis of the 1985 and 2002 data.

Using the experimentally derived grade-specific digestion coefficients for herring led to an unacceptable proportion of estimated sizes (weights and lengths) that were larger that the known size range. There was no obvious explanation for this anomaly. As an *ad hoc* solution to rectify this problem, the grade 1 digestion coefficient was applied to all otolith measurements regardless of their assigned grade; this generated sizes that were mostly within the known size range. This anomaly is discussed further below.

In scats where a sub-sample of the otoliths identified for a species had been measured, the fish weight represented by each unmeasured otolith was assumed equal to the mean weight of all measured otoliths of that species in that scat. This was also assumed for broken otoliths without an appropriate measurement. If there were no measured otoliths of that species in that scat, the mean fish weight of that species over all scats was used.

Fish/cephalopod weight was estimated from undigested otolith/beak size using allometric equations from the literature (primarily Leopold *et al.* (2001), but in about 10% of species Brown and Pierce 1998, Clarke 1986; Härkönen 1986, Santos *et al.* 2001, GJ Pierce and MB Santos pers comm). For prey species for which no equations were available the equations for the closest matching species were used; these species were all minor prey. For unidentified gadid otoliths, the relationship between otolith size and fish weight for haddock was used. For unidentified flatfish, the relationship for plaice was used. Analysis using alternative relationships showed that the results were insensitive to these choices. The

allometric relationships used were the same as previously used for analysis of the 1985 and 2002 data.

For each region/season, the estimated weights of prey represented by all fish otoliths and cephalopod beaks in the sample scats were summed within species. To account for species-specific differences in complete digestion, the weight estimated for each prey species was adjusted using experimentally derived recovery rates (Grellier and Hammond 2006). Where no experimental data were available, values for group-specific (e.g. gadids, flatfish) or the closest matching species were used. Diet composition was estimated as the percentage that each species contributed to the total estimated weight consumed.

Data in quarters in which few scats (less than 60) were collected were combined with data from another quarter or were not used.

3.4 Estimation of Prey Consumption

To estimate the amount of prey consumed by grey seals, the assumption was made that, on average, they met their estimated energy requirements (as described by Sharples *et al.* 2009).

The estimated weight of each prey species in each region/season was multiplied by energy density values from the literature (Murray and Burt 1977 for fish, GJ Pierce and MB Santos pers comm for cephalopods) to represent diet composition in units of energy.

The estimated energy requirement for the population of grey seals in each region/season was calculated as the product of:

- The estimated average daily energy requirement of 5,497 Kcals (Sparling and Smout 2003), as previously used for analysis of 1985 and 2002 data.
- The estimated number of seals in the region, calculated from Thomas (2014) and supplemented by additional data representing breeding sites not regularly monitored (Duck and Morris, 2014; see Table 2).
- The number of days in the season (quarter or half of the year).

The population energy requirement for a region/season was allotted to each prey species in the diet according to the estimated proportion of energy represented.

The final step was to divide the prey-specific energy requirement by prey-specific energy density to generate estimated prey consumption for each prey species by weight. Seasons were summed within regions to give estimates of annual prey consumption. Regions were combined into North Sea (ICES Subarea IV) and west of Scotland (ICES Division VIa).

Table 2

Estimates of regional population size used to estimate consumption of prey by grey seals. The estimates are based on the population size estimated from pup counts at regularly surveyed sites (Thomas 2014). The North Sea estimate was divided into Central and Southern North Sea based on the proportion of pup production. Estimates were augmented to account for additional pups born at sites that were not monitored regularly; Duck and Morris 2014). Population size for pups born at non-regularly monitored sites was obtained by multiplying pup production by a pup multiplier, calculated as estimated population size dived by pup production, for the most appropriate region. There were no diet data for Shetland in 1985.

	Total population size		
Region	**1985**	**2002**	**2010**
Shetland		2,292	1,784
Orkney and northern North Sea	19,742	47,619	50,640
Central North Sea	4,336	12,382	15,375
Southern North Sea	139	2,646	6,801
North Sea total	27,681	64,938	74,600
Inner Hebrides	4,721	8,593	8,923
Outer Hebrides	22,418	27,844	27,664
West of Scotland total	27,139	36,437	36,587

3.5 Estimation of Variability

Variances of estimates of diet composition and consumption were obtained using the method described by Hammond and Rothery (1996) and implemented in Hammond and Grellier (2006), and Hammond and Harris (2006).

Sampling error was estimated using non-parametric bootstrap resampling with scat as the sampling unit. Each region/season dataset was resampled 1,000 times. Measurement error was estimated using parametric resampling of the coefficients describing the relationships used to obtain estimates of diet composition and prey consumption from otolith/beak measurements. All coefficients were resampled at each bootstrap replicate.

Measurement error included variability associated with (a) estimating undigested otolith/beak size from partially digested measurements via species- or grade-specific digestion coefficients; (b) estimating fish/cephalopod weight from estimated undigested otolith/beak size via species-specific allometric relationships; (c) accounting for complete digestion of otoliths/beaks using estimated recovery rates; and (d) estimating consumption using an estimate of daily energy requirement and estimates of population size of grey seals.

Estimates of the variability associated with experimentally derived estimates of digestion coefficients and recovery rates were taken from Grellier and Hammond (2006). Estimates of

variability associated with otolith size - fish weight relationships were taken from Leopold *et al.* (2001), and from GJ Pierce and MB Santos (pers comm) for beak size - cephalopod weight relationships. It was assumed that seal population estimates and the estimate of grey seal daily energy requirement had coefficients of variation of 10%.

For estimates of diet composition and prey consumption within each region/season, 95% confidence limits were estimated as the 2.5%-ile and 97.5%-ile of the bootstrapped distributions. To estimate confidence limits of diet composition or prey consumption combined across seasons and/or regions, bootstrapped estimates were combined for each replicate (diet composition averaged, prey consumption summed) and the percentiles taken from the distribution of combined values.

3.6 Length of Consumed Fish

Equations relating fish length to otolith size from Leopold *et al.* (2001) were used to generate frequency distributions of estimated fish length for the main prey species in the diet.

4 Results

4.1 Diet Data

In total, 2,205 scats containing hard parts were processed yielding 68,465 otoliths and beaks, of which 35,514 were measured (Table 3). The number of scats collected was generally smaller in quarters 2 and 3, partly because of sample collection effort but primarily because grey seals tend to haul out at the water's edge, partially in the water, at some sites at these times of year. No scats were collected in the Outer Hebrides in quarters 2 and 3. Only a handful of scats were collected in the Inner Hebrides and Shetland in quarter 3.

The number of otoliths and beaks of all species recovered from scats is detailed by region in Table 4. Sandeel otoliths were by far the most common hard parts recovered. Other commonly found prey species included: Norway pout, poor cod and unidentified *Trisopterus* spp.; saithe, whiting, cod, haddock, rockling and unidentified gadid; plaice and unidentified flatfish; dragonet, goby, sea scorpion and bullrout; and herring.

Table 3

Number of grey seal scat samples (containing hard parts that were processed) collected by region and quarter in 2010/11 and the total number of hard parts (fish otoliths and cephalopod beaks) recovered.

Region	Quarter	Number of scats	Total otoliths/beaks	Measured otoliths/beaks
Inner Hebrides	1	125	2,373	1,927
Inner Hebrides	2	18	104	103
Inner Hebrides	3	1	24	24
Inner Hebrides	4	189	2,531	2,129
Inner Hebrides	Total	333	5,032	4,183
Outer Hebrides	1	136	2,117	1,474
Outer Hebrides	2	0	0	
Outer Hebrides	3	0	0	
Outer Hebrides	4	138	3,183	1,945
Outer Hebrides	Total	274	5,300	3,419
Shetland	1	143	2,899	1,879
Shetland	2	60	560	531
Shetland	3	3	35	34
Shetland	4	63	748	593
Shetland	Total	269	4,242	3,037
Orkney and Northern North Sea	1	406	13,432	7,023
Orkney and Northern North Sea	2	57	1,332	767
Orkney and Northern North Sea	3	30	2,763	888
Orkney and Northern North Sea	4	249	6,853	3,756
Orkney and Northern North Sea	Total	742	24,380	12,434
Central North Sea	1	151	11,071	4,086
Central North Sea	2	25	293	176
Central North Sea	3	102	4,500	1,944
Central North Sea	4	105	4,051	1,638
Central North Sea	Total	383	19,915	7,844
Southern North Sea	1	71	3,325	1,583
Southern North Sea	2	81	4,334	1,832
Southern North Sea	3	31	1,319	820
Southern North Sea	4	21	618	362
Southern North Sea	Total	204	9,596	4,597
TOTAL		2,205	68,465	35,514

Table 4. Number of all fish otoliths and cephalopod beaks recovered from grey seal scats in 2010/11 for each region, grouped by prey type.

Prey group	Prey species	Inner Hebrides	Outer Hebrides	Shetland	Orkney and northern North Sea	Central North Sea	Southern North Sea	TOTAL
	Saithe	72	71	592	800	43	0	1,578
	Whiting	85	52	14	122	511	395	1,179
	Cod	97	48	71	549	105	56	926
	Unid gadid	192	91	96	258	112	37	786
	Haddock	56	30	6	479	47	1	619
	Unid rockling	57	28	26	387	5	32	535
	Ling	102	40	36	123	1	0	302
	Blue whiting	152	5	0	0	0	0	157
	Hake	5	14	8	1	0	0	28
	Tadpole fish	2	6	8	8	0	0	24
	Forkbeard	0	13	0	1	2	2	18
	4-brd rockling	9	0	1	1	2	0	13
	Silvery pout	2	5	2	1	0	0	10
	Pollock	0	7	1	1	0	0	9
	Seasnail	0	0	0	1	0	5	6
	Torsk	0	4	0	0	0	0	4
	3-brd rockling	1	0	0	0	0	0	1
Gadid	**TOTAL**	**832**	**414**	**861**	**2,732**	**828**	**528**	**6,195**
	Norway pout	1,074	787	234	1,355	16	0	3,466
	Poor cod	643	446	317	1,143	50	52	2,651
	Unid *Trisopterus*	378	323	50	555	29	15	1,350
	Pout whiting	1	0	0	1	0	23	25
Trisopterus	**TOTAL**	**2,096**	**1,556**	**601**	**3,054**	**95**	**90**	**7,492**
Sandeel	**TOTAL sandeel**	**1,288**	**2,904**	**1,950**	**16,358**	**18,148**	**7,575**	**48,223**
	Plaice	29	14	21	381	283	233	961
	Unid flatfish	88	46	19	232	159	127	671
	Lemon sole	38	30	24	89	46	45	272
	Dab	7	4	39	109	61	30	250
	Dover sole	1	0	0	2	0	220	223
	Witch	41	10	7	13	5	0	76
	Thickback sole	39	1	9	26	0	0	75
	Megrim	3	45	9	10	0	0	67
	Unid sole	30	1	5	8	1	1	46
	Topknot	30	1	0	9	0	0	40
	Long rough dab	7	0	2	8	18	0	35
	Flounder	0	0	0	28	2	1	31
	Norway topknot	6	4	7	12	2	0	31
	Brill	0	0	0	0	0	3	3
	Solenette	0	1	0	2	0	0	3
	Scaldfish	3	0	0	0	0	0	3
Flatfish	**TOTAL**	**322**	**157**	**142**	**929**	**577**	**660**	**2,787**
	Dragonet	239	59	149	88	18	212	765
	Goby	2	0	260	102	15	53	432
	Butterfish	0	0	0	19	3	30	52
	Lesser weever	0	0	0	4	0	19	23
Sandy benthic	**TOTAL**	**241**	**59**	**409**	**213**	**36**	**314**	**1,272**

Prey group	Prey species	Inner Hebrides	Outer Hebrides	Shetland	Orkney and northern North Sea	Central North Sea	Southern North Sea	TOTAL
	Sea scorpion	32	3	19	144	2	273	473
	Bullrout	21	0	58	271	42	48	440
	Hooknose	4	0	4	31	52	12	103
	Grey gurnard	2	1	0	7	0	0	10
	Lumpsucker	0	1	0	8	0	0	9
	Gurnard	2	0	0	6	0	0	8
	Unid Cottidae	0	0	0	1	4	0	5
Scorpion fish	**TOTAL**	**61**	**5**	**81**	**468**	**100**	**333**	**1,048**
	Herring	26	83	41	203	13	47	413
	Sprat	1	0	0	11	93	27	132
	Mackerel	3	21	9	46	1	0	80
	Argentine	4	0	6	30	0	0	40
	Horse mackerel	1	2	4	11	0	1	19
	Pilchard	0	0	0	1	0	0	1
Pelagic	**TOTAL**	**35**	**106**	**60**	**302**	**107**	**75**	**685**
Salmonid	**TOTAL**	**0**	**0**	**5**	**0**	**0**	**0**	**5**
	Loligo	23	26	15	108	7	10	189
	Eledone	73	34	9	33	0	0	149
	Sepiola spp.	5	3	45	21	4	0	78
	Unid Squid	8	5	17	30	5	0	65
	Sepiolids	1	1	13	32	0	0	47
	Sepietta spp.	4	1	4	7	0	0	16
	Rossia	0	0	10	1	0	1	12
	Ommastrephidae	0	1	1	1	0	1	4
	Alloteuthis spp.	0	0	0	2	0	0	2
Cephalopod	**TOTAL**	**114**	**71**	**114**	**235**	**16**	**12**	**562**
	Eelpout	0	0	0	32	6	6	44
	Ballan wrasse	14	6	7	12	0	0	39
	Unid wrasse	3	12	0	19	1	0	35
	Cuckoo wrasse	6	4	0	8	0	0	18
	Conger eel	11	5	0	1	0	0	17
	Snake blenny	0	0	0	14	0	0	14
	Unknown fish	9	1	0	0	0	0	10
	Atlantic catfish	0	0	9	0	0	0	9
	Garfish	0	0	2	3	0	0	5
	Bass	0	0	0	0	0	3	3
	Unid roundfish	0	0	1	0	0	0	1
	Eel	0	0	0	0	1	0	1
Other	**TOTAL**	**43**	**28**	**19**	**89**	**8**	**9**	**196**
TOTAL		**5,032**	**5,300**	**4,242**	**24,380**	**19,915**	**9,596**	**68,465**

4.2 Diet Composition

Estimated grey seal diet composition, expressed as percentage of the diet by weight, is given in Table 5 for the main prey species in the diet for each season in each region. Table 6 shows the estimated diet composition combined into prey groups. Estimates of precision (95% confidence limits) are given in Appendices 1 and 2.

In the Western Isles, the diet of grey seals in 2010/11 was dominated by sandeel and gadid prey, particularly cod and ling. Dragonet was a major contributor to the diet in the Inner Hebrides. Although not a large component of the diet, the contribution of *Trisopterus* spp. and cephalopods to the diet in the Inner and Outer Hebrides was greater than for other regions.

In the Northern Isles, the diet was also dominated by sandeel and gadid prey, particularly saithe and cod. In Orkney and the northern North Sea, sandeels made up around half of the diet. Bullrout was also important in the diet, particularly in Shetland. Flatfish contributed less to the diet in the Northern Isles than in other regions. Shetland was the only region where there were any salmonids in the diet (half of one percent).

In the North Sea, grey seal diet was dominated by sandeels, particularly in the central North Sea, where the only other prey species contributing more than a very small amount to the diet were plaice and cod. In the southern North Sea, the diet was more varied and included whiting, cod, plaice, Dover sole, dragonet and sea scorpion but in relatively small amounts. Flatfish were more prevalent in the diet in the southern North Sea than in other areas.

Table 5

Estimated diet composition for main prey species, grouped by prey type, and all other species grouped as “Other”, expressed as % of the diet by weight, for each region and season in 2010/11.

Data for quarters 2 and 3 were not analysed in the Inner Hebrides (very small sample size) or Outer Hebrides (no samples). Data for quarters 2 and 3 were combined for Shetland, Orkney and the northern North Sea, and the central North Sea. Data for quarters 3 and 4 were combined for the southern North Sea. Figures for Year are weighted by the length of season, as appropriate. Estimates of precision are given in Appendix 1.

(a) Western Isles

	Inner Hebrides			**Outer Hebrides**		
Prey species	**Q1**	**Q4**	**Year**	**Q1**	**Q4**	**Year**
Cod	10.3	12.1	11.2	15.4	5.9	10.7
Whiting	1.8	0.9	1.3	0.9	1.1	1.0
Haddock	1.7	1.5	1.6	1.1	3.0	2.1
Saithe	1.1	3.2	2.2	4.2	4.6	4.4
Ling	4.3	12.6	8.4	11.0	5.0	8.0
Rockling	0.0	6.4	3.2	1.2	0.1	0.6
Poor cod	2.3	2.5	2.4	2.5	1.9	2.2
Norway pout	4.9	4.9	4.9	3.5	5.1	4.3
Sandeel	30.4	15.4	22.9	38.8	38.1	38.5
Plaice	0.6	1.5	1.0	0.5	0.3	0.4
Lemon sole	0.4	2.9	1.7	2.1	1.0	1.5
Dover sole	0.3	0.0	0.1	0.0	0.0	0.0
Megrim	0.0	0.5	0.3	0.9	5.9	3.4
Dragonet	17.0	6.4	11.7	3.6	3.4	3.5
Bullrout	7.6	0.2	3.9	0.0	0.0	0.0
Sea scorpion	0.6	1.6	1.1	0.2	0.0	0.1
Herring	0.8	0.9	0.8	2.1	3.7	2.9
Eledone	1.4	3.7	2.6	1.0	1.5	1.2
Loligo	1.2	1.4	1.3	3.7	0.5	2.1
Ballan wrasse	0.2	14.4	7.3	0.8	7.1	4.0
Other	13.0	7.0	10.0	6.5	11.8	9.2

(b) Northern Isles

	Shetland				Orkney and northern North Sea			
Prey species	**Q1**	**Q2+3**	**Q4**	**Year**	**Q1**	**Q2+3**	**Q4**	**Year**
Cod	6.9	7.3	13.7	8.8	15.3	4.2	11.7	8.9
Whiting	0.4	0.2	0.3	0.3	0.5	0.6	0.5	0.5
Haddock	0.3	1.0	0.0	0.6	7.4	2.7	4.0	4.2
Saithe	19.8	22.7	9.5	18.7	6.5	10.0	4.9	7.9
Ling	3.2	0.6	6.2	2.7	3.0	0.4	1.0	1.2
Rockling	0.1	3.7	0.0	1.9	1.1	2.0	1.3	1.6
Poor cod	2.3	2.1	0.1	1.7	1.4	1.2	1.9	1.4
Norway pout	0.9	1.5	1.7	1.4	1.3	4.0	1.3	2.6
Sandeel	32.8	15.8	35.1	24.9	39.0	61.2	45.1	51.6
Plaice	0.5	0.3	1.4	0.7	2.0	1.0	4.2	2.0
Lemon sole	2.1	1.4	1.5	1.6	1.3	0.5	1.1	0.8
Dover sole	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0
Megrim	0.4	1.6	3.9	1.8	0.5	0.0	0.0	0.1
Dragonet	14.6	2.1	0.8	4.9	2.3	0.9	1.3	1.3
Bullrout	2.8	22.4	13.2	15.2	6.0	3.7	9.7	5.8
Sea scorpion	0.4	4.1	1.4	2.5	1.8	0.5	0.4	0.8
Herring	0.7	8.9	0.7	4.8	4.0	1.4	0.6	1.8
Eledone	0.2	0.4	1.8	0.7	0.3	0.0	1.1	0.3
Loligo	0.7	0.0	2.5	0.8	1.7	1.1	2.7	1.6
Ballan wrasse	0.7	0.0	0.0	0.2	0.0	0.1	0.2	0.1
Other	10.1	4.0	6.1	6.0	4.4	4.6	7.2	5.2

(c) North Sea

	Central North Sea				Southern North Sea			
Prey species	**Q1**	**Q2+3**	**Q4**	**Year**	**Q1**	**Q2**	**Q3+4**	**Year**
Cod	4.2	0.5	7.0	3.0	3.4	5.4	1.8	3.1
Whiting	2.1	1.9	2.6	2.1	1.3	6.0	7.2	5.4
Haddock	1.0	0.1	1.9	0.8	0.0	0.05	0.0	0.01
Saithe	0.1	3.8	0.0	1.9	0.0	0.0	0.0	0.0
Ling	0.0	0.0	0.7	0.2	0.0	0.0	0.0	0.0
Rockling	0.0	0.0	0.3	0.1	0.5	0.05	0.0	0.1
Poor cod	0.2	0.1	0.1	0.1	0.2	0.1	0.0	0.1
Norway pout	0.04	0.0	0.1	0.04	0.0	0.0	0.0	0.0
Sandeel	82.4	80.4	70.8	78.5	49.3	71.7	56.7	58.6
Plaice	2.2	4.7	5.4	4.3	1.0	4.1	12.7	7.6
Lemon sole	0.9	3.7	0.4	2.2	1.7	0.4	2.0	1.5
Dover sole	0.0	0.0	0.0	0.0	10.8	3.9	3.1	5.2
Megrim	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Dragonet	0.5	1.1	0.9	0.9	4.3	2.8	8.4	6.0
Bullrout	1.5	0.5	4.2	1.7	5.8	1.0	1.3	2.4
Sea scorpion	0.02	0.0	0.0	0.004	17.1	0.4	1.6	5.2
Herring	0.1	0.9	0.0	0.4	1.3	0.0	0.7	0.7
Eledone	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Loligo	0.1	0.1	0.6	0.3	0.0	0.2	1.4	0.8
Ballan wrasse	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other	4.7	2.2	4.9	3.5	3.3	3.9	2.9	3.3

Table 6: Estimated diet composition for prey groups, expressed as % of the diet by weight, for each region and season in 2010/11. Figures for Year are weighted by the length of season, as appropriate. Estimates of precision are given in Appendix 2.

(a) Western Isles

	Inner Hebrides			Outer Hebrides		
Prey group	**Q1**	**Q4**	**Year**	**Q1**	**Q4**	**Year**
Gadid	25.3	38.0	31.6	37.9	27.1	32.5
Trisopterus	7.6	7.6	7.6	6.2	7.5	6.8
Sandeel	30.4	15.4	22.9	38.8	38.1	38.5
Flatfish	7.2	9.3	8.2	4.7	8.7	6.7
Sandy benthic	17.0	6.4	11.7	3.6	3.4	3.5
Scorpion fish	8.4	1.9	5.2	1.1	0.0	0.5
Pelagic	1.3	0.9	1.1	2.1	5.8	3.9
Salmonid	0.0	0.0	0.0	0.0	0.0	0.0
Cephalopod	2.7	5.1	3.9	4.7	2.0	3.3
Other	0.2	15.3	7.7	0.9	7.5	4.2

(b) Northern Isles

	Shetland				Orkney and N North Sea			
Prey group	**Q1**	**Q2+3**	**Q4**	**Year**	**Q1**	**Q2+3**	**Q4**	**Year**
Gadid	31.5	36.8	33.6	34.7	34.4	20.4	24.0	24.8
Trisopterus	3.3	3.6	2.0	3.1	2.8	5.5	3.4	4.3
Sandeel	32.8	15.8	35.1	24.9	39.0	61.2	45.1	51.6
Flatfish	4.8	5.3	7.4	5.7	6.0	2.3	9.8	5.1
Sandy benthic	14.7	2.1	0.9	4.9	2.4	1.3	1.3	1.6
Scorpion fish	3.5	26.5	14.6	17.8	8.6	4.2	10.5	6.9
Pelagic	1.9	9.3	1.9	5.6	4.6	2.9	1.7	3.0
Salmonid	1.8	0.0	0.0	0.4	0.0	0.0	0.0	0.0
Cephalopod	1.2	0.7	4.4	1.7	2.0	1.1	3.9	2.0
Other	4.6	0.0	0.1	1.2	0.2	1.1	0.3	0.7

(c) North Sea

	Central North Sea				Southern North Sea			
Prey group	**Q1**	**Q2+3**	**Q4**	**Year**	**Q1**	**Q2**	**Q3+4**	**Year**
Gadid	7.6	6.6	12.9	8.4	5.2	11.7	9.6	9.0
Trisopterus	0.3	0.1	0.3	0.2	0.2	0.9	0.0	0.3
Sandeel	82.4	80.4	70.8	78.5	49.3	71.7	56.7	58.6
Flatfish	5.6	10.3	9.0	8.8	15.1	10.6	19.5	16.2
Sandy benthic	0.5	1.1	0.9	0.9	4.4	2.9	8.9	6.3
Scorpion fish	2.3	0.5	4.7	2.0	23.1	1.6	3.0	7.7
Pelagic	1.2	0.9	0.0	0.8	2.0	0.0	0.8	0.9
Salmonid	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cephalopod	0.1	0.1	0.7	0.3	0.0	0.5	1.4	0.8
Other	0.1	0.02	0.7	0.2	0.7	0.1	0.01	0.2

The width of estimated confidence intervals for each species or prey group (Appendices 1 and 2) is related to sample size (number of scats and number of prey remains), to the estimated percentage consumed, and to how the prey remains were distributed among scats. Estimated confidence intervals are wide for most prey species in most seasons and regions. Precision (confidence in the results) is greater (a) for annual estimates than for seasonal estimates in each region, (b) for major components of the diet, especially sandeel, and (c) for prey groups than for prey species. Precision is greatest for estimates of diet composition for prey groups for the whole year (Table 6 and Appendix 2).

Means of bootstrapped distributions were within a few percent of estimates from the original data for most species. The exceptions were saithe and sea scorpion, which had particularly wide 95% confidence intervals but were typically not major contributors to the diet (except saithe in the Northern Isles, Table 5b). 95% confidence intervals often included zero when a species percentage contribution to the diet was very small.

4.3 Prey Consumption

Estimated annual prey consumption by grey seals in 2010/11 is given in Table 7 for the main species in the diet. Estimates of precision (95% confidence limits) are given in Appendix 3. The pattern in estimates of prey consumption follows that of diet composition but taking population size in each region into account. Thus, in the North Sea (ICES Subarea IV), the large majority of prey consumed were taken from Orkney and the northern and central North Sea. West of Scotland (ICES Division VIa), the large majority of prey consumed were taken from the Outer Hebrides. In the North Sea overall, greater than half the annual consumption was of sandeel (73,000 t). Other prey species that grey seals consumed in large quantities in the North Sea included cod (9,580 t), saithe (8,100 t), bullrout (6,500 t), haddock (4,100 t) and plaice (3,800 t). West of Scotland, sandeels were also the most consumed species (24,000 t); others consumed in large quantities included cod (7,600 t) and ling (5,800 t).

The same considerations regarding the width of estimated confidence intervals (Appendix 3) apply as for estimates of diet composition. Precision is greater for regions with larger sample sizes, for major components of the diet, especially sandeel, and for combinations of regions.

Overall, grey seals were estimated to have consumed 129,200 t (95% confidence interval: 114,800 - 149,400 t) of prey in the North Sea (ICES Subarea IV) and 70,300 t (95% confidence interval: 60,000 - 84,000 t) of prey west of Scotland (ICES Division VIa) in the 12 months from April 2010 to March 2011 and a grand total of 199,500 t (95% confidence interval: 181,200 - 225,500 t).

Table 7. Estimated grey seal annual consumption (tonnes) of main prey, grouped by prey type, by region and summed in the North Sea and west of Scotland in 2010/11. TOTAL (all spp) is the total estimated consumption of all prey species in the diet, not the sum over species in the Table. For the Inner and Outer Hebrides, consumption estimates for quarters 1 and 4 were extrapolated to the whole year because there were very few or no, respectively, data from quarters 2 and 3. Estimates of precision are given in Appendix 3.

	North Sea					West of Scotland			
Prey species	**Shetland**	**Orkney and northern North Sea**	**Central North Sea**	**Southern North Sea**	**Total North Sea ICES subarea IV**	**Inner Hebrides**	**Outer Hebrides**	**Total West of Scotland ICES Division VIa**	**TOTAL**
Cod	307	8,157	759	358	9,580	2,063	5,569	7,632	17,213
Whiting	10	476	515	626	1,626	241	529	770	2,396
Haddock	20	3,837	195	1	4,053	290	1,068	1,358	5,410
Saithe	652	6,953	471	0	8,075	411	2,282	2,694	10,769
Ling	92	1,103	45	0	1,240	1,593	4,178	5,771	7,011
Rockling	66	1,435	21	16	1,537	625	335	960	2,497
Poor cod	58	1,281	34	8	1,381	437	1,155	1,592	2,973
Norway pout	49	2,315	9	0	2,373	896	2,213	3,109	5,482
Sandeel	863	45,836	19,223	6,771	72,693	4,111	19,988	24,099	96,792
Plaice	23	1,859	1,048	886	3,816	196	203	399	4,214
Lemon sole	55	755	529	178	1,517	319	799	1,119	2,635
Dover sole	0	29	0	610	639	24	0	24	663
Megrim	65	122	0	0	187	51	1,769	1,820	2,007
Unid flatfish	28	727	320	148	1,224	411	434	846	2,069
Dragonet	168	1,221	218	695	2,302	2,085	1,813	3,899	6,200
Bullrout	535	5,247	420	276	6,478	677	0	677	7,155
Sea scorpion	88	749	1	612	1,450	207	63	270	1,720
Herring	169	1,652	108	80	2,009	151	1,492	1,643	3,653
Eledone	24	324	0	0	347	482	636	1,119	1,466
Loligo	28	1,499	65	89	1,680	233	1,083	1,316	2,997
Ballan wrasse	6	91	0	0	97	1,418	2,037	3,454	3,551
TOTAL (all spp)	3,485	89,639	24,524	11,585	129,233	18,311	51,969	70,279	199,512

4.4 Prey Length

Plots of estimated length-frequency of most of the main prey species in grey seal diet in 2010/11 are shown for the North Sea (ICES Subarea IV) and west of Scotland (ICES Division VIa) in Appendix 4, Figures 1-8. Distributions have not been plotted where sample sizes are small. The lengths are estimated and thus subject to measurement error, although using grade specific digestion coefficients should help to minimise error. In the length-frequency plots the errors are more apparent in the tails of the distributions, the extent of which should not therefore be over-interpreted.

Where data allow a comparison, the distributions show that fish consumed were of a similar estimated size west of Scotland and in the North Sea for haddock, poor cod, lemon sole and dragonet. Cod, whiting, saithe, ling, Norway pout and sandeel consumed were estimated to be larger, on average, west of Scotland than in the North Sea. Herring were estimated to be larger, on average, in the North Sea than west of Scotland.

The estimated lengths are consistent with the known size ranges of the prey consumed. The estimated lengths of sandeel range up to 30 cm and greater (Figure 7) because grey seals consume greater sandeel (*Hyperoplus lanceolatus*) as well as *Ammodytes marinus* and other smaller species that typically cannot be distinguished from each other from partially digested otoliths.

4.5 Comparison of Results for 2010/11 with 1985 and 2002

Table 8 shows how estimated grey seal diet composition has changed compared to 1985 and 2002. As described above, estimated 95% confidence intervals are typically wide so any inferences regarding temporal changes must be made cautiously. Taking the precision of estimates into account, diet composition west of Scotland appears to have changed relatively little from 1985 to 2002 to 2010/11 (Table 8a). However, some patterns do emerge for other regions.

In the Northern Isles, change in diet composition was characterised by a marked decline in the estimated percentage of sandeel in Shetland (from 71% in 2002 to 25% in 2010/11) and a more gradual decline in Orkney (from 82% to 61% to 52% in 1985, 2002 and 2010/11, respectively) (Table 8b). Concurrent changes in other prey groups were: an increase in gadids in Shetland between 2002 and 2010/11 and the maintenance in 2010/11 of the increase in gadids between 1985 and 2002 in Orkney; and an increase in sandy benthic and scorpion fish in Shetland.

In the central North Sea, the change in sandeel and gadids was the reverse of that seen in the Northern Isles. Gadids declined markedly from 30% to 22% to 8% in 1985, 2002 and 2010/11, respectively, but sandeel increased from 64% and 62% in 1985 and 2002, respectively, to 79% in 2010/11 (Table 8c).

In the southern North Sea, estimated diet composition in 2010/11 was much more similar to 1985 than 2002. The strongest pattern was the return in 2010/11 to approximately 50% sandeel and approximately 15% sandy benthic and scorpion fish, after a reverse of this pattern in 2002 (Table 8c).

Table 8

Estimated diet composition for prey groups, expressed as % of the diet by weight, for 1985, 2002 and 2010/11. Shetland was not sampled in 1985.

(a) Western Isles

	Inner Hebrides			Outer Hebrides		
Prey group	**1985**	**2002**	**2010/11**	**1985**	**2002**	**2010/11**
Gadid	64.4	43.6	31.6	26.6	36.0	32.5
Trisopterus	6.3	9.0	7.6	4.2	2.1	6.8
Sandeel	13.0	13.8	22.9	54.2	35.5	38.5
Flatfish	3.8	4.6	8.2	12.0	14.7	6.7
Sandy benthic	0.9	7.2	11.7	0.2	2.0	3.5
Scorpion fish	1.1	9.3	5.2	0.1	0.6	0.5
Pelagic	8.3	8.3	1.1	1.7	5.2	3.9
Salmonid	0.0	0.0	0.0	0.0	0.0	0.0
Cephalopod	0.0	3.7	3.9	0.0	2.9	3.3
Other	2.2	0.6	7.7	1.0	0.9	4.2

(b) Northern Isles

	Shetland			Orkney and northern North Sea		
Prey group	**1985**	**2002**	**2010/11**	**1985**	**2002**	**2010/11**
Gadid		16.4	34.7	9.7	19.8	24.8
Trisopterus		0.4	3.1	0.2	1.2	4.3
Sandeel		71.4	24.9	81.9	61.0	51.6
Flatfish		0.8	5.7	3.0	6.0	5.1
Sandy benthic		0.0	4.9	0.3	0.9	1.6
Scorpion fish		2.9	17.8	4.3	7.8	6.9
Pelagic		1.1	5.6	0.5	0.3	3.0
Salmonid		1.5	0.4	0.0	0.2	0.0
Cephalopod		1.0	1.7	0.0	2.4	2.0
Other		4.5	1.2	0.2	0.4	0.7

(c) North Sea

	Central North Sea			Southern North Sea		
Prey group	**1985**	**2002**	**2010/11**	**1985**	**2002**	**2010/11**
Gadid	29.5	22.3	8.4	14.6	17.5	9.0
Trisopterus	1.2	0.3	0.2	0.8	1.0	0.3
Sandeel	63.9	62.2	78.5	46.3	17.9	58.6
Flatfish	3.3	6.1	8.8	18.3	10.9	16.2
Sandy benthic	0.6	3.1	0.9	7.8	21.9	6.3
Scorpion fish	1.3	4.7	2.0	11.0	29.4	7.7
Pelagic	0.1	0.1	0.8	1.3	0.8	0.9
Salmonid	0.0	0.0	0.0	0.0	0.0	0.0
Cephalopod	0.0	0.9	0.3	0.0	0.5	0.8
Other	0.0	0.2	0.2	0.0	0.1	0.2

4.6 Grey Seal Consumption Compared to Estimated Size of Commercial Fish Stocks

Table 9 presents information on estimated annual prey consumption by grey seals compared to the estimated size of fish stocks assessed by ICES in Subarea IV (North Sea, including Shetland and Orkney) and Division VIa (west of Scotland) in 1985, 2002 and 2010.

In Subarea IV, annual consumption by grey seals as a percentage of stock size is estimated to be small; the highest figures are for cod (3.5% in 2002, 5.1% in 2010). In Division VIa, estimated annual consumption as a percentage of stock size is small for herring but larger for whiting (around 10% in 2002 and 2010). For cod, the estimated annual consumption as a percentage of stock size is very large (> 100% in 2010).

For the first time, estimates of prey consumption are available for harbour seals (Wilson and Hammond 2015). Adding harbour seal consumption to that of grey seals increases estimated annual consumption as a percentage of stock size in 2010 only slightly in the North Sea (ICES Subarea IV); the largest difference is for Dover sole, which increases from 2.1% to 3.5%. Larger differences occur west of Scotland (ICES Division VIa). Herring increases from 1.0% to 2.0%, whiting increases from 10% to around 50% and cod increases to greater than 200%.

These anomalous results for cod are discussed under section 5.4.

5 Discussion

5.1 Representativeness of Scat Samples

Sampling was achieved in all major areas where grey seals haul out around Scotland (and the east coast of England) and seasonal coverage was adequate in most seasons. Some combination of quarters was necessary in analysis, as had been done for some regions in

2002, (Hammond and Grellier 2006, Hammond and Harris 2006). However, inadequate samples for analysis were collected in quarters 2 and 3 in the Inner and Outer Hebrides. Grey seal scats are difficult to collect in most places in summer and the same problem occurred in the Inner Hebrides in 2002 (Hammond and Harris 2006). The lack of samples in summer 2010 in the Outer Hebrides was a result of limited resources.

Diet composition and prey consumption for the whole year west of Scotland have therefore been estimated based only on data from October to March. It is unknown whether the lack of summer samples west of Scotland could have caused bias in estimates of annual prey consumption in Division VIa. However, results for 2002 for the Outer Hebrides (where the large majority of grey seals haul out west of Scotland) indicate that a large bias is unlikely, and the confidence intervals are wide (Hammond and Harris 2006).

More generally, it is also unknown whether the scat samples are representative of the populations of grey seals at large. Possible reasons for unrepresentative samples have previously been discussed: relative over-sampling of foraging in inshore waters; failure to consume the heads of large prey; and secondary prey digestion (Hammond and Grellier 2006, Hammond and Harris 2006), where it was concluded that anything more than minor bias was unlikely. Sampling protocol was the same in 2010/11 as in 2002 and it is expected the same to be true for the current study.

Table 9. Estimated grey seal annual prey consumption (in tonnes) in 1985, 2002 and 2010 and estimates of annual consumption by seals as a percentage of estimated stock size for fish stocks assessed by ICES in Subarea IV (North Sea) and Division VIa (west of Scotland). Estimates of grey seal population size are shown in italics.

Estimates of grey seal prey consumption for 1985 and 2002 were previously presented in Hammond and Grellier (2006) and Hammond and Harris (2006); these have been updated with the latest estimates of grey seal population size for those years from Table 2. Estimates of total fish stock biomass (TSB) taken from ICES (2014). Stock size estimates for plaice and Dover sole in Subarea IV were only available for Spawning Stock Biomass (SSB).

	Grey seal consumption (t)			**Total Stock Biomass (TSB) (t)**			**Consumption as a % of estimated stock size**		
	1985	**2002**	**2010**	**1985**	**2002**	**2010**	**1985**	**2002**	**2010**
North Sea (Subarea IV)									
Grey seal population	*27,681*	*64,938*	*74,600*						
Cod	3,161	8,337	9,580	554,599	234,920	189,662	0.57%	3.5%	5.1%
Whiting	598	2,646	1,626	968,423	780,089	563,120	0.06%	0.34%	0.29%
Norway pout	44	810	2,373	479,543	362,388	821,416	0.01%	0.22%	0.29%
Plaice (SSB)	582	4,967	3,816	338,997	197,124	465,482	0.17%	2.5%	0.82%
Dover sole (SSB)	51	222	187	40,476	30,546	30,201	0.13%	0.73%	2.1%
Herring	26	180	1,680	4,110,273	5,728,705	4,077,522	0.001%	0.003%	0.05%
Sandeel (Central & South)	4,870	14,233	25,995	1,448,813	1,824,909	2,639,942	0.34%	0.78%	1.0%
Grey seal population (Central & South)	*4,475*	*15,028*	*22,176*						
West of Scotland (Division VIa)									
Grey seal population	*27,139*	*36,437*	*36,587*						
Cod	5.063	8,824	7,632	36,318	11,461	4,228	14%	77%	181%
Whiting	1,438	1,686	770	79,504	15,139	7,618	1.8%	11%	10%
Herring	556	1,933	1,316	351,363	290,419	164,421	0.16%	0.67%	1.0%
North Sea and west of Scotland									
Grey seal population	*54.820*	*101,375*	*111,187*						
Haddock	2,136	13,364	5,410	1,163,470	881,780	565,620	0.18%	1.5%	1.0%
Saithe	2,025	2,554	10,769	491,143	549,809	420,400	0.41%	0.46%	2.6%

5.2 Diet Composition

The coefficients and relationships used to correct for partial and complete digestion and to estimate fish/cephalopod weight from otolith/beak size were the same (except for herring) as used for analysis of the 2002 data and reanalysis of the 1985 data (Grellier and Hammond 2006, Hammond and Grellier 2006, Hammond and Harris 2006). These coefficients were estimated from robust experiments and there is no reason to believe that they are substantially biased. Thus, there is confidence that the results are generally robust.

The anomaly described above for herring is unexplained but is most likely related to correction for partial digestion. The corrected results reflect the size distribution in sampled herring and should therefore be robust, whatever the cause of the problem. However, this anomaly requires further investigation.

5.3 Prey Consumption

Estimates of prey consumption depend on the assumption that grey seals, on average, meet their energy requirements. Grey seal populations are stable west of Scotland and in Orkney and are still increasing in the North Sea (Duck and Morris 2014, Thomas 2014). Thus, it is very unlikely that they are not meeting their energy requirement.

Estimates of prey consumption are also dependent on robust estimates of population size and energy requirements. Data collected during the pupping season and population size estimated regionally from these data, was used (Duck and Morris 2014, Thomas 2014, Table 2). However, grey seals are known to be distributed differently to some extent out with the pupping season so, although the estimates of annual prey consumption in ICES Division VIa (west of Scotland) and Subarea IV (North Sea) are likely to be more or less unbiased, seasonal and regional estimates may not be. Lonergan *et al.* (2011) have presented regional estimates of grey seal population size based on summer haul-out counts corrected for the proportion of seals not on land from telemetry data. These estimates, normalised to sum to total population size from each ICES area, could be used to investigate the extent of any bias in regional and seasonal estimates of prey consumption.

Similarly, a single estimate of average daily energy requirement for grey seals was used (Sparling and Smout 2003). Again, estimates of annual consumption are likely to be more or less unbiased but seasonal results may be improved if seasonal estimates of energy requirement are used. The same applies to values of energy density of prey species.

5.4 Grey Seal Consumption as a Percentage of Fish Stock size in ICES Division VIa

The estimated annual prey consumption by grey seals as a percentage of fish stock size in Division VIa west of Scotland is about 10% for whiting and much greater than 100% for cod

(Table 9). These figures increase markedly if estimated harbour seal prey consumption is included. Although a possible contributing cause of these high figures could be bias unaccounted for in diet analysis, such bias would have to be unfeasibly large to lead to a substantially different result.

Instead, focusing on cod, the most likely explanation is that total stock biomass estimated by the assessment is only a fraction of the total amount of cod in Division VIa. The stock assessment is primarily driven by data on catches and discards, 90% of which are taken from an area that is almost exclusively off the continental shelf; in the absence of other information estimated stock biomass is considered to apply to the whole of Division VIa (R. Catarino pers comm). In contrast, the areas predicted to be used for foraging by grey and harbour seals, as determined from telemetry data, are almost exclusively on the continental shelf (Jones *et al*. 2015). Between the area where 90% of the cod are taken and the seal foraging areas, there is only a very small overlap for grey seals and no overlap for harbour seals. Thus, the seals and the fishery remove cod from largely different areas and the estimated stock biomass relates primarily to the area where there are no seals.

Knowledge of the extent of the cod population estimated by the stock assessment and of the movements of cod found off the shelf (seasonal or otherwise) is incomplete. Components of the west coast cod population(s) may be targeted by both the fishery and the seals. However, the high spatial separation of the fishery and seal foraging is at least a partial explanation for how the estimated consumption by seals can be so large relative to the size of the assessed stock.

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8 Appendices

8.1 Appendix 1: Estimated lower and upper 95% confidence limits of estimated diet composition for main prey species (see Table 5 for point estimates)

(a) Inner Hebrides

	Q1		Q4		Year	
Prey species	**lower**	**upper**	**lower**	**upper**	**lower**	**upper**
Cod	3.8	18.6	5.3	21.7	6.3	17.6
Whiting	0.4	4.0	0.4	1.6	0.6	2.4
Haddock	0.2	5.0	0.7	2.5	0.6	3.1
Saithe	0.0	9.8	0.1	19.2	0.2	12.2
Ling	1.7	8.2	5.9	22.3	4.7	13.3
Rockling	0.0	0.1	2.6	12.5	1.3	6.3
Poor cod	1.2	4.0	1.3	4.3	1.5	3.5
Norway pout	2.2	8.6	1.7	9.5	2.6	7.6
Sandeel	11.0	54.1	5.6	33.1	11.4	37.1
Plaice	0.0	1.8	0.3	2.8	0.3	1.8
Lemon sole	0.1	1.0	0.6	7.9	0.5	4.3
Dover sole	0.0	1.0	-	-	0.0	0.5
Megrim	0.0	0.0	0.0	1.2	0.0	0.6
Dragonet	8.0	30.3	2.6	12.2	6.4	19.2
Bullrout	0.4	22.7	0.0	0.8	0.3	11.5
Sea scorpion	0.1	2.4	0.3	6.4	0.3	3.8
Herring	0.1	2.1	0.3	1.7	0.3	1.6
Eledone	0.3	3.1	1.8	6.1	1.4	4.1
Loligo	0.2	2.6	0.2	3.4	0.4	2.5
Ballan wrasse	0.0	0.5	0.0	36.4	0.1	18.3

(b) Outer Hebrides

	Q1		Q4		Year	
Prey species	**lower**	**upper**	**lower**	**upper**	**lower**	**upper**
Cod	2.6	34.1	1.7	12.4	3.4	20.4
Whiting	0.4	1.9	0.3	2.2	0.5	1.7
Haddock	0.0	2.9	0.9	6.1	0.6	3.8
Saithe	0.3	34.7	0.4	36.6	0.9	24.3
Ling	3.4	22.5	1.0	11.1	3.3	14.4
Rockling	0.3	2.9	0.0	0.2	0.2	1.5
Poor cod	0.8	5.8	0.9	3.2	1.1	3.9
Norway pout	0.9	7.8	2.1	9.1	2.2	7.0
Sandeel	15.0	67.4	15.9	59.8	20.8	56.8
Plaice	0.0	1.5	0.0	0.7	0.1	0.9
Lemon sole	0.5	5.5	0.2	2.9	0.5	3.5
Dover sole	-	-	-	-	-	-
Megrim	0.1	2.7	2.5	11.0	1.6	6.0
Dragonet	0.8	8.4	0.7	7.4	1.4	6.4
Bullrout	-	-	-	-	-	-
Sea scorpion	0.0	1.1	-	-	0.0	0.5
Herring	0.8	4.5	1.5	6.8	1.6	4.6
Eledone	0.3	2.2	0.6	2.6	0.6	2.0
Loligo	1.3	7.3	0.0	1.2	0.8	4.0
Ballan wrasse	0.0	2.2	0.0	21.2	0.0	11.3

(c) Shetland

	Q1		Q2+3		Q4		Year	
Prey species	**lower**	**upper**	**lower**	**upper**	**lower**	**upper**	**lower**	**upper**
Cod	1.2	17.8	2.1	14.8	3.8	26.8	4.1	13.7
Whiting	0.1	1.0	0.0	0.6	0.0	1.0	0.1	0.5
Haddock	0.0	0.9	0.0	3.1	-	-	0.0	1.6
Saithe	3.1	65.1	3.5	67.8	1.0	49.3	6.7	44.7
Ling	0.8	6.8	0.0	2.4	1.4	12.6	1.1	4.6
Rockling	0.0	0.2	0.9	8.0	-	-	0.5	4.0
Poor cod	0.8	4.3	0.6	4.3	0.0	0.4	0.7	2.8
Norway pout	0.2	2.2	0.3	3.6	0.0	5.8	0.4	2.8
Sandeel	9.1	57.8	2.9	40.0	10.3	58.0	11.8	37.8
Plaice	0.1	1.1	0.0	1.0	0.0	5.1	0.1	1.6
Lemon sole	0.5	5.5	0.0	4.5	0.0	5.4	0.5	3.7
Dover sole	-	-	-	-	-	-	-	-
Megrim	0.0	1.4	0.0	6.1	0.7	9.6	0.3	4.3
Dragonet	4.4	27.1	0.0	6.9	0.0	3.1	1.8	8.7
Bullrout	0.4	8.3	3.1	43.8	2.5	31.8	5.1	26.8
Sea scorpion	0.0	2.0	0.4	14.3	0.0	6.7	0.5	7.8
Herring	0.1	1.4	1.3	20.6	0.0	2.2	1.0	10.6
Eledone	0.0	0.6	0.0	1.4	0.3	3.9	0.2	1.3
Loligo	0.2	1.6	-	-	0.0	6.8	0.1	1.8
Ballan wrasse	0.1	1.5	-	-	-	-	0.0	0.4

(d) Orkney and northern North Sea

	Q1		Q2+3		Q4		Year	
Prey species	**lower**	**upper**	**lower**	**upper**	**lower**	**upper**	**lower**	**upper**
Cod	7.3	24.8	0.9	11.6	5.2	20.2	5.4	13.4
Whiting	0.2	0.9	0.1	1.4	0.2	0.8	0.3	1.0
Haddock	2.4	14.2	0.3	8.6	1.5	7.6	2.0	7.5
Saithe	0.8	35.0	1.2	49.5	0.6	30.4	2.5	29.7
Ling	1.3	5.0	0.0	1.7	0.3	1.9	0.6	2.0
Rockling	0.3	2.4	0.0	6.3	0.3	2.9	0.4	3.9
Poor cod	0.7	2.3	0.4	3.0	0.5	4.2	0.8	2.4
Norway pout	0.5	2.6	0.5	9.9	0.2	3.7	0.8	5.6
Sandeel	18.6	60.5	23.1	81.8	21.2	66.7	30.4	63.4
Plaice	0.9	3.3	0.3	2.3	1.4	8.4	1.1	3.2
Lemon sole	0.5	2.8	0.0	1.7	0.4	2.5	0.4	1.6
Dover sole	0.0	0.4	-	-	-	-	0.0	0.1
Megrim	0.1	1.2	-	-	-	-	0.0	0.3
Dragonet	1.0	4.2	0.0	3.2	0.4	2.7	0.6	2.5
Bullrout	2.1	13.2	0.0	13.9	3.3	21.1	2.7	11.5
Sea scorpion	0.4	6.6	0.0	3.3	0.1	1.8	0.2	2.5
Herring	1.7	6.8	0.2	3.6	0.2	1.3	0.9	3.2
Eledone	0.1	0.6	-	-	0.4	1.9	0.2	0.6
Loligo	0.7	2.9	0.1	3.0	1.1	5.0	0.9	2.8
Ballan wrasse	-	-	0.0	0.4	0.0	0.4	0.0	0.3

(e) Central North Sea

	Q1		Q2+3		Q4		Year	
Prey species	**lower**	**upper**	**lower**	**upper**	**lower**	**upper**	**lower**	**upper**
Cod	0.9	11.0	0.0	1.7	2.3	16.0	1.3	5.8
Whiting	0.8	5.0	0.3	5.2	1.1	5.3	1.1	4.0
Haddock	0.2	2.8	0.0	0.5	0.4	4.8	0.3	1.6
Saithe	0.0	0.6	0.0	26.2	-	-	0.0	13.1
Ling	-	-	-	-	0.0	2.9	0.0	0.7
Rockling	-	-	-	-	0.0	1.3	0.0	0.3
Poor cod	0.0	0.6	0.0	0.4	0.0	0.4	0.0	0.3
Norway pout	0.0	0.1	-	-	0.0	0.3	0.0	0.1
Sandeel	63.6	92.1	56.3	90.8	50.2	84.7	63.9	85.5
Plaice	0.5	5.3	1.6	12.0	2.0	11.0	2.2	8.1
Lemon sole	0.2	2.8	0.8	10.4	0.0	1.5	0.7	5.5
Dover sole	-	-	-	-	-	-	-	-
Megrim	-	-	-	-	-	-	-	-
Dragonet	0.1	1.3	0.0	3.6	0.0	2.6	0.2	2.2
Bullrout	0.1	6.0	0.0	2.4	0.9	12.4	0.5	4.1
Sea scorpion	0.0	0.1	-	-	-	-	0.0	0.02
Herring	0.0	0.2	0.2	2.1	-	-	0.1	1.1
Eledone	-	-	-	-	-	-	-	-
Loligo	0.0	0.5	0.0	0.6	0.0	1.8	0.0	0.6
Ballan wrasse	-	-	-	-	-	-	-	-

(f) Southern North Sea

	Q1		Q2		Q3+4		Year	
Prey species	**lower**	**upper**	**lower**	**upper**	**lower**	**upper**	**lower**	**upper**
Cod	0.2	9.7	0.3	14.6	0.0	4.9	1.0	5.9
Whiting	0.4	2.6	1.8	15.6	1.3	17.2	1.9	11.1
Haddock	-	-	0.0	0.2	-	-	0.0	0.1
Saithe	-	-	-	-	-	-	-	-
Ling	-	-	-	-	-	-	-	-
Rockling	0.0	1.4	0.0	0.1	-	-	0.0	0.4
Poor cod	0.1	0.3	0.0	0.3	-	-	0.0	0.1
Norway pout	-	-	-	-	-	-	-	-
Sandeel	21.3	71.9	47.2	86.2	29.1	81.3	39.8	72.6
Plaice	0.0	3.6	1.5	8.5	2.1	29.3	2.3	15.9
Lemon sole	0.5	4.1	0.0	1.5	0.2	6.5	0.5	3.9
Dover sole	4.3	20.9	1.6	8.5	0.6	7.8	2.9	8.7
Megrim	-	-	-	-	-	-	-	-
Dragonet	1.7	8.0	0.9	6.2	2.7	20.2	2.8	12.1
Bullrout	1.7	15.2	0.2	3.1	0.0	4.4	1.0	5.2
Sea scorpion	4.4	48.8	0.1	2.1	0.0	8.0	1.9	13.3
Herring	0.1	3.9	-	-	0.1	1.7	0.2	1.4
Eledone	-	-	-	-	-	-	-	-
Loligo	-	-	0.0	0.7	0.1	4.2	0.1	2.1
Ballan wrasse	-	-	-	-	-	-	-	-

8.2 Appendix 2: Estimated lower and upper 95% confidence limits of estimated diet composition for prey groups (see Table 6 for point estimates)

(a) Inner Hebrides

	Q1		Q4		Year	
Prey group	**lower**	**upper**	**lower**	**upper**	**lower**	**upper**
Gadid	14.7	40.8	23.2	57.1	22.2	43.6
Trisopterus	3.9	12.3	3.7	13.1	4.8	10.9
Sandeel	11.0	54.1	5.6	33.1	11.4	37.1
Flatfish	3.4	12.3	4.8	14.9	5.1	11.9
Sandy benthic	8.0	30.3	2.6	12.2	6.4	19.2
Scorpion fish	0.8	24.2	0.5	6.7	1.0	13.2
Pelagic	0.2	3.1	0.4	1.8	0.5	2.1
Salmonid	-	-	-	-	-	-
Cephalopod	1.1	5.1	2.6	8.4	2.3	5.8
Other	0.0	0.5	0.7	36.9	0.4	18.5

(b) Outer Hebrides

	Q1		Q4		Year	
Prey group	**lower**	**upper**	**lower**	**upper**	**lower**	**upper**
Gadid	14.9	64.6	14.3	53.4	19.0	51.2
Trisopterus	2.4	12.5	3.3	12.5	3.8	10.4
Sandeel	15.0	67.4	15.9	59.8	20.8	56.8
Flatfish	2.0	9.7	4.1	14.5	4.0	10.5
Sandy benthic	0.8	8.4	0.7	7.4	1.4	6.4
Scorpion fish	0.0	3.9	-	-	0.0	2.0
Pelagic	0.9	4.5	2.6	12.4	2.1	7.2
Salmonid	-	-	-	-	-	-
Cephalopod	1.9	8.9	0.8	3.5	1.8	5.6
Other	0.0	2.4	0.1	21.5	0.2	11.5

(c) Shetland

	Q1		Q2+3		Q4		Year	
Prey group	**lower**	**upper**	**lower**	**upper**	**lower**	**upper**	**lower**	**upper**
Gadid	12.7	72.3	15.6	75.3	17.1	65.1	22.4	56.9
Trisopterus	1.2	5.8	1.2	7.2	0.0	6.3	1.3	5.2
Sandeel	9.1	57.8	2.9	40.0	10.3	58.0	11.8	37.8
Flatfish	1.7	9.4	0.6	13.3	2.2	15.2	2.6	10.3
Sandy benthic	4.5	27.2	0.0	6.9	0.0	3.2	1.9	8.8
Scorpion fish	0.6	9.6	4.4	50.1	2.8	34.7	6.4	30.8
Pelagic	0.6	4.8	1.4	20.7	0.3	4.1	1.6	11.4
Salmonid	0.0	6.9	-	-	-	-	0.0	1.7
Cephalopod	0.4	2.2	0.1	1.8	0.6	9.8	0.6	3.1
Other	0.6	11.2	-	-	0.0	0.7	0.2	2.8

(d) Orkney and northern North Sea

	Q1		Q2+3		Q4		Year	
Prey group	**lower**	**upper**	**lower**	**upper**	**lower**	**upper**	**lower**	**upper**
Gadid	19.8	56.8	7.1	58.5	12.8	45.6	16.9	44.9
Trisopterus	0.0	0.04	1.1	12.8	1.1	6.8	1.8	8.1
Sandeel	0.2	0.6	23.1	81.8	21.2	66.7	30.4	63.4
Flatfish	0.0	0.1	0.7	5.1	4.1	16.9	3.1	7.3
Sandy benthic	0.0	0.04	0.2	3.8	0.4	2.7	0.8	2.9
Scorpion fish	0.0	0.2	0.4	15.1	4.0	22.0	3.7	13.2
Pelagic	0.0	0.1	0.6	7.7	0.5	3.6	1.5	5.6
Salmonid	-	-	-	-	-	-	-	-
Cephalopod	0.0	0.03	0.2	3.0	1.7	6.5	1.2	3.2
Other	0.0	0.003	0.2	2.9	0.1	0.7	0.2	1.6

(e) Central North Sea

	Q1		Q2+3		Q4		Year	
Prey group	**lower**	**upper**	**lower**	**upper**	**lower**	**upper**	**lower**	**upper**
Gadid	2.7	17.3	1.3	28.3	5.7	24.9	4.5	20.3
Trisopterus	0.1	0.7	0.0	0.4	0.1	0.6	0.1	0.4
Sandeel	63.6	92.1	56.3	90.8	50.2	84.7	63.9	85.5
Flatfish	2.3	11.8	4.0	24.2	3.9	17.0	5.1	16.0
Sandy benthic	0.1	1.3	0.0	3.6	0.0	2.6	0.2	2.2
Scorpion fish	0.3	7.5	0.0	2.4	1.1	13.0	0.7	4.6
Pelagic	0.3	3.4	0.3	2.3	-	-	0.3	1.6
Salmonid	-	-	-	-	-	-	-	-
Cephalopod	0.0	0.5	0.0	0.6	0.0	1.9	0.1	0.6
Other	0.0	0.2	0.0	0.1	0.0	2.9	0.0	0.8

(f) Southern North Sea

	Q1		Q2		Q3+4		Year	
Prey group	**lower**	**upper**	**lower**	**upper**	**lower**	**upper**	**lower**	**upper**
Gadid	1.4	12.1	3.7	25.8	2.4	20.7	4.2	15.9
Trisopterus	0.1	0.4	0.1	2.5	0.0	0.0	0.1	0.7
Sandeel	21.3	71.9	47.2	86.2	29.1	81.3	39.8	72.6
Flatfish	6.5	27.2	5.1	20.5	6.3	37.6	8.8	26.0
Sandy benthic	1.7	8.1	1.1	6.5	2.8	21.7	3.0	12.7
Scorpion fish	8.8	52.5	0.5	4.8	0.2	10.8	3.8	16.2
Pelagic	0.4	5.4	-	-	0.2	1.8	0.3	1.9
Salmonid	-	-	-	-	-	-	-	-
Cephalopod	-	-	0.0	1.6	0.1	4.2	0.1	2.2
Other	0.0	2.0	0.0	0.3	0.0	0.1	0.0	0.5

Appendix 3: Estimated lower and upper 95% confidence limits of estimated prey consumption for main prey species (see Table 7 for point estimates)

(a) Western Isles – ICES Division VIa

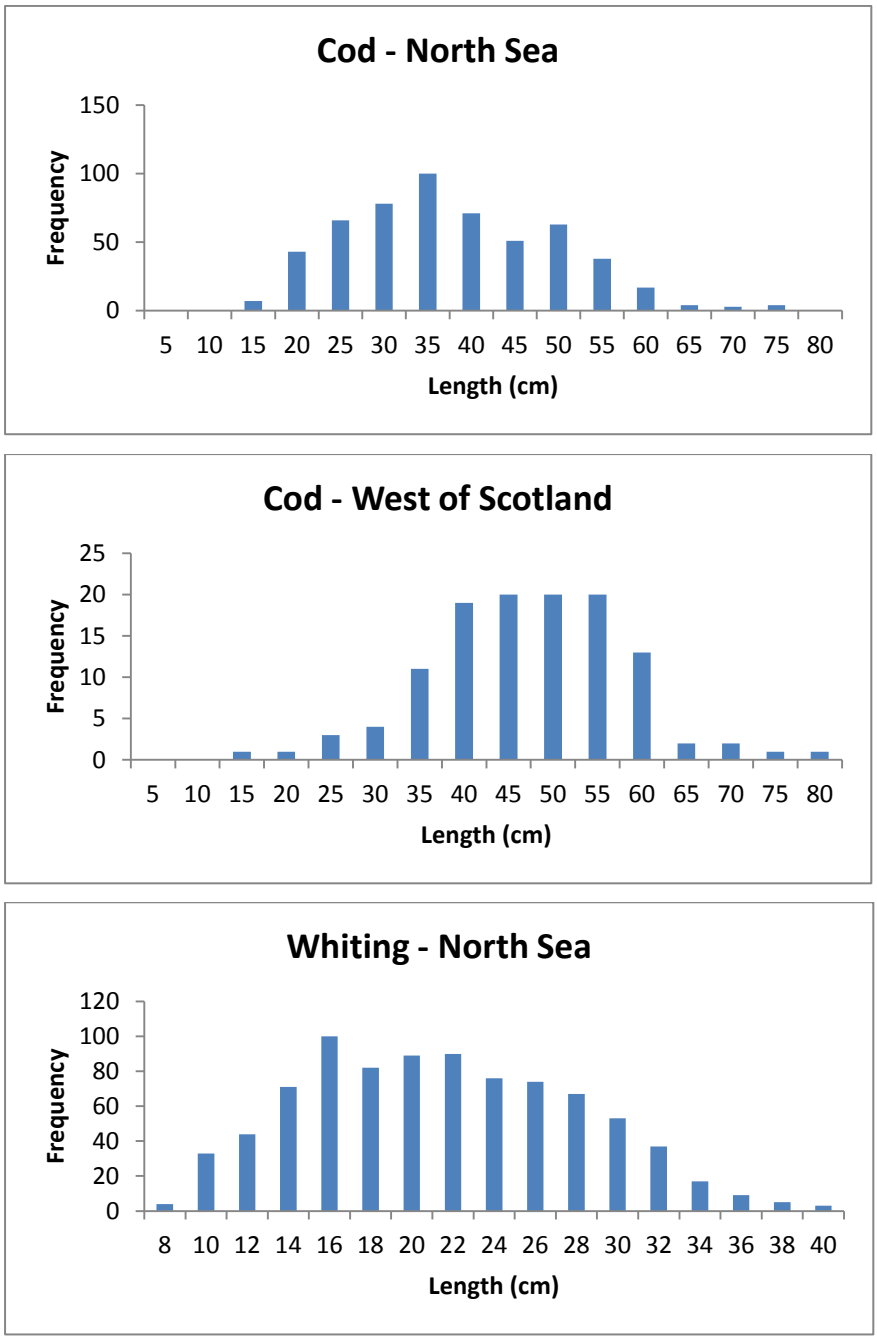
	Inner Hebrides		Outer Hebrides		Division VIa	
Prey species	**lower**	**upper**	**lower**	**upper**	**lower**	**upper**
Cod	1,080	3,423	1,736	11,792	3,542	13,937
Whiting	102	465	236	989	425	1,252
Haddock	107	599	310	2,117	574	2,446
Saithe	44	2,542	461	14,832	724	15,446
Ling	828	2,669	1,675	8,352	3,121	10,077
Rockling	241	1,290	92	813	477	1,719
Poor cod	266	700	529	2,188	940	2,585
Norway pout	481	1,485	1,113	3,859	1,869	4,915
Sandeel	2,141	6,478	11,371	28,594	14,617	32,540
Plaice	51	356	42	494	166	701
Lemon sole	94	839	273	1,843	484	2,338
Dover sole	0	92	-	-	0	92
Megrim	0	123	792	3,271	853	3,302
Unid. flatfish	201	709	190	821	508	1,344
Dragonet	1,084	3,568	659	3,542	2,335	6,084
Bullrout	41	2,117	-	-	41	2,117
Sea scorpion	56	696	0	304	85	841
Herring	61	288	802	2,567	925	2,757
Eledone	251	795	317	1,165	690	1,678
Loligo	72	479	421	2,324	615	2,513
Ballan wrasse	17	3,832	0	6,298	122	7,912

(b) North Sea – ICES Subarea IV (NS = North Sea)

	Shetland		Orkney and N NS		Central NS		Southern NS		Subarea IV	
Prey species	**lower**	**upper**	**lower**	**upper**	**lower**	**upper**	**lower**	**upper**	**lower**	**upper**
Cod	136	502	4,792	13,051	316	1,628	114	742	6,046	14,619
Whiting	2	19	242	923	260	1,059	212	1,447	1,036	2,694
Haddock	0	57	1,777	7,265	73	421	0	6	1,970	7,493
Saithe	224	1,847	2,104	30,693	1	3,342	-	-	3,312	32,682
Ling	36	170	533	1,963	0	197	-	-	657	2,112
Rockling	16	144	388	3,631	0	90	2	44	493	3,739
Poor cod	25	101	680	2,286	10	77	4	17	786	2,363
Norway pout	13	103	689	5,142	2	22	-	-	736	5,201
Sandeel	434	1,269	29,766	57,465	15,139	22,578	4,763	8,415	55,072	84,170
Plaice	3	61	954	3,184	521	2,193	235	2,072	2,547	5,784
Lemon sole	17	127	329	1,483	170	1,496	58	501	924	2,813
Dover sole	-	-	0	88	-	-	331	1,075	353	1,105
Megrim	12	156	25	297	-	-	-	-	63	385
Unid. flatfish	0	101	351	1,266	135	715	68	299	766	1,966
Dragonet	62	311	523	2,391	58	549	311	1,532	1,430	3,879
Bullrout	170	1,001	2,360	10,816	117	1,085	115	622	3,426	12,227
Sea ccorpion	18	303	212	2,371	0	5	209	1,748	698	3,420
Herring	36	372	803	2,990	32	284	23	184	1,134	3,340
Eledone	6	50	135	564	-	-	-	-	158	589
Loligo	4	68	814	2,651	9	166	8	268	972	2,856
Ballan wrasse	1	14	11	251	-	-	-	-	15	256

8.3 Appendix 4: Estimated length-frequency of prey species in grey seal diet in 2010/11

Figure 1: Estimated length frequencies of cod and whiting consumed by grey seals in 2010/11. Minimum landing sizes are 35 cm for cod and 27 cm for whiting.



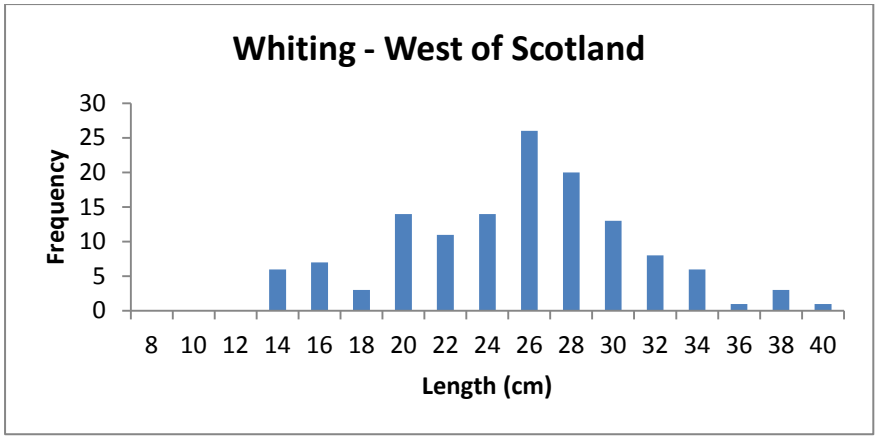
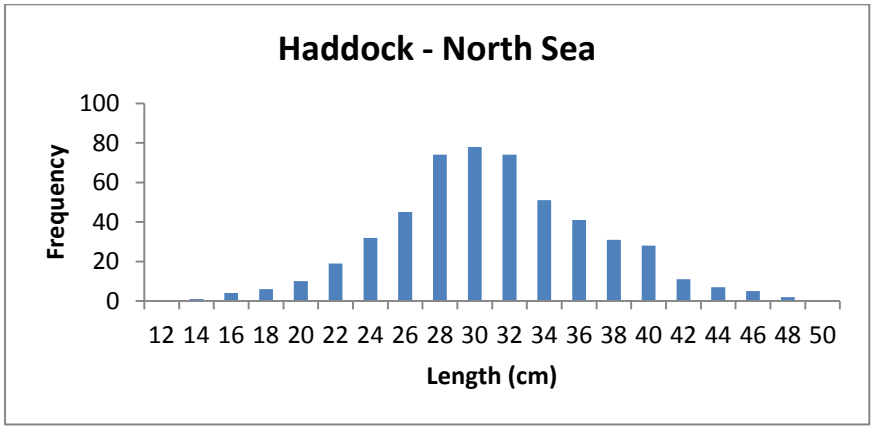
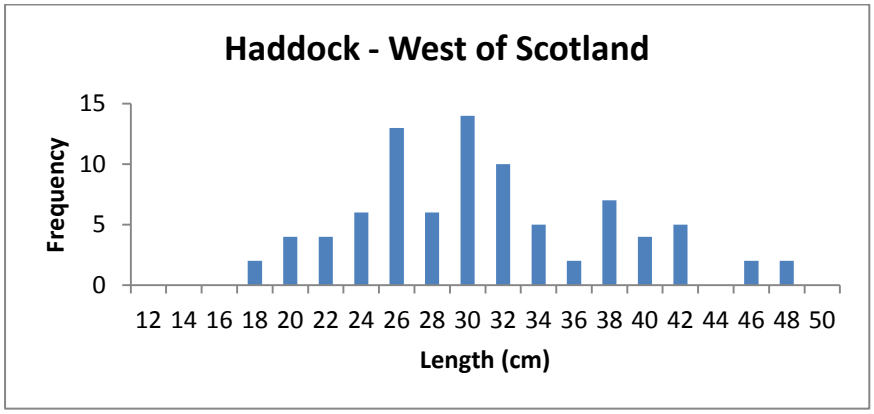
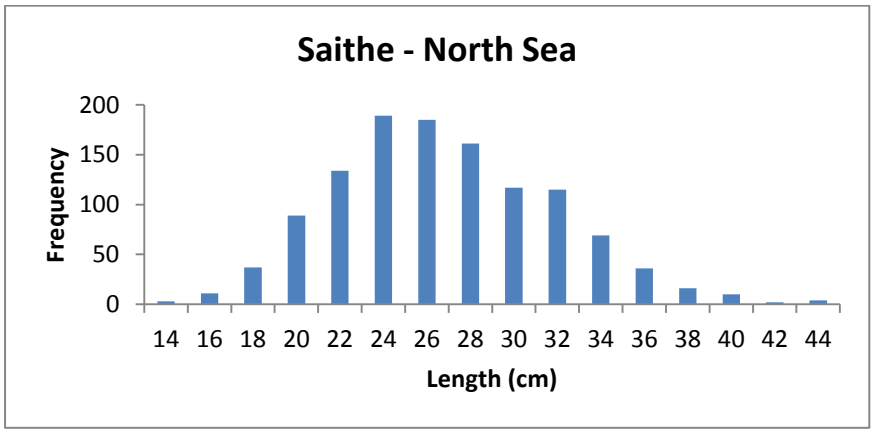

Whiting - West of Scotland
Frequency
30
25
20
15
10
5
0
8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40
Length (cm)

Figure 2: Estimated length frequencies of haddock and saithe consumed by grey seals in 2010/11. Minimum landing sizes are 30cm for haddock and 35cm for saithe.







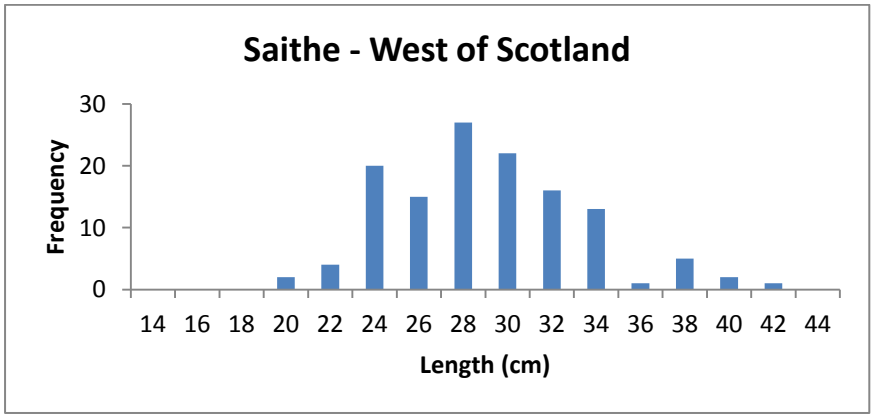


Figure 3: Estimated length frequencies of ling and blue whiting consumed by grey seals in 2010/11. Minimum landing size is 63cm for ling.

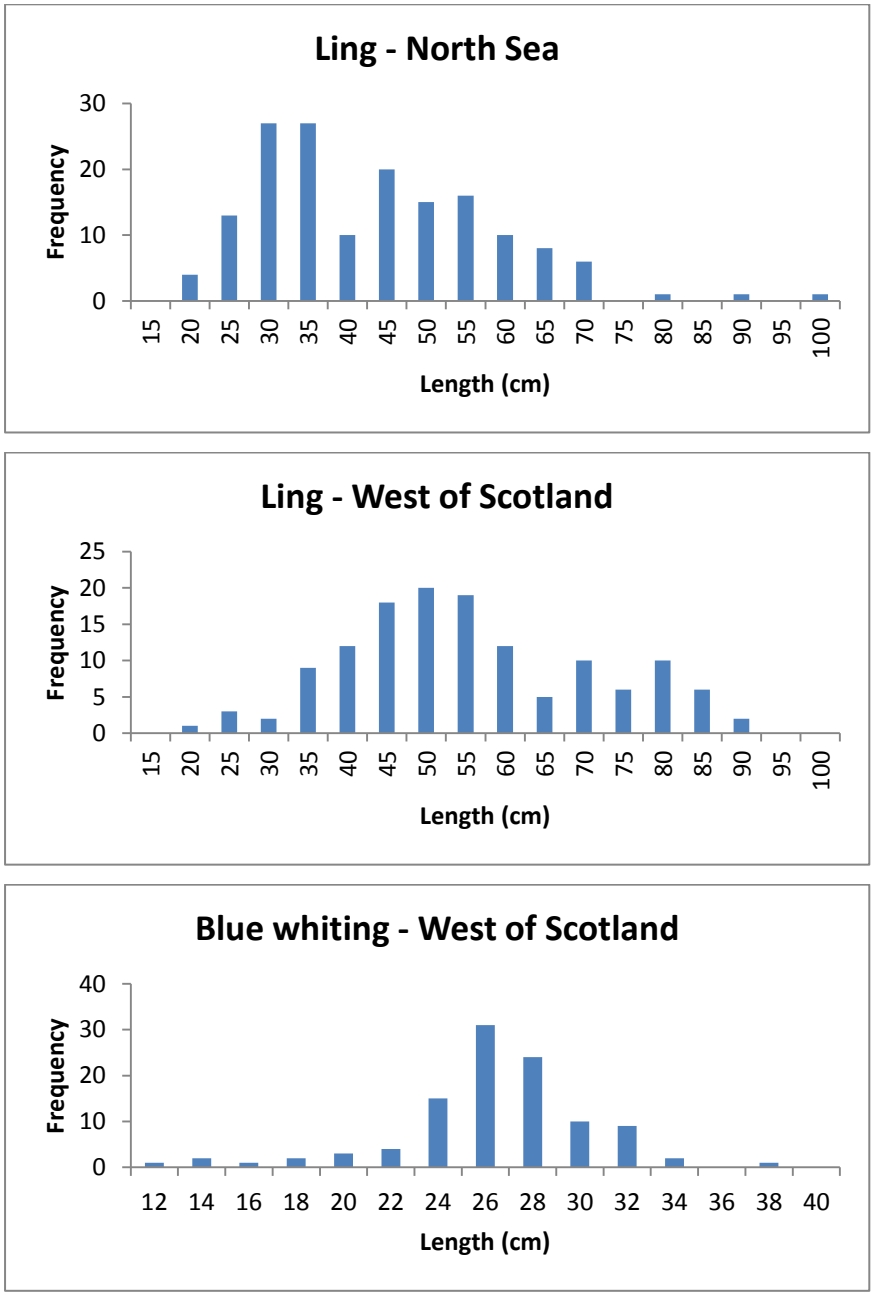
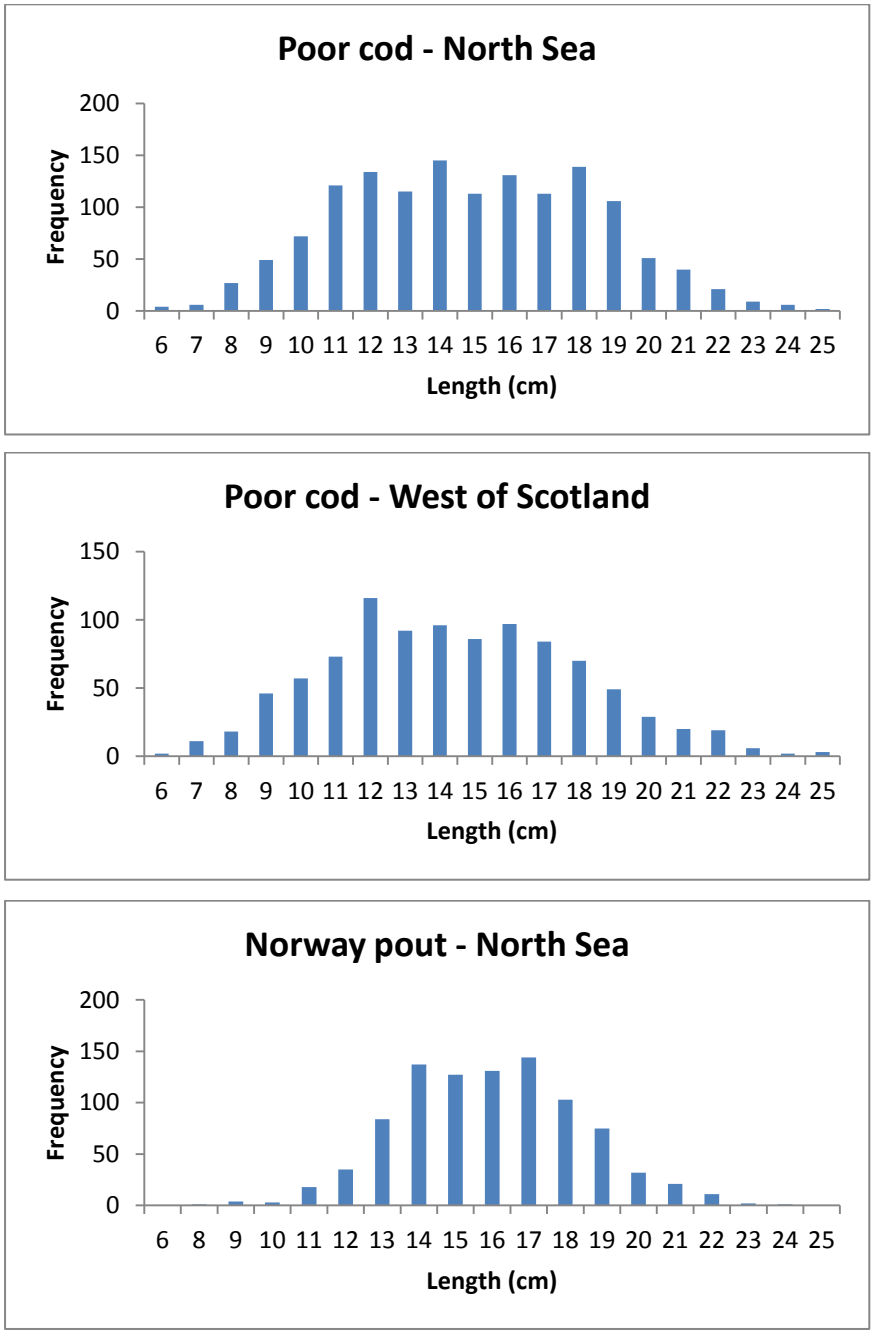


Figure 4: Estimated length frequencies of poor cod and Norway pout consumed by grey seals in 2010/11.



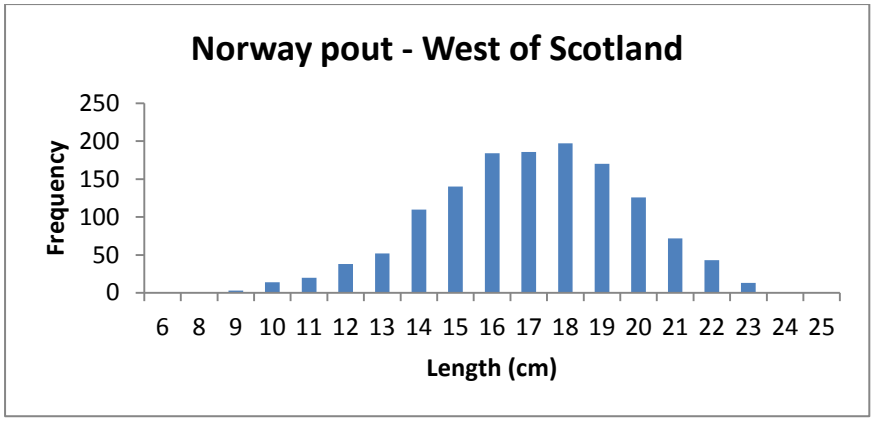

Norway pout - West of Scotland
Frequency
250
200
150
100
50
0
6 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
Length (cm)

Figure 5: Estimated length frequencies of plaice and Dover sole consumed by grey seals in 2010/11. Minimum landing sizes are 27cm for plaice and 24cm for Dover sole.

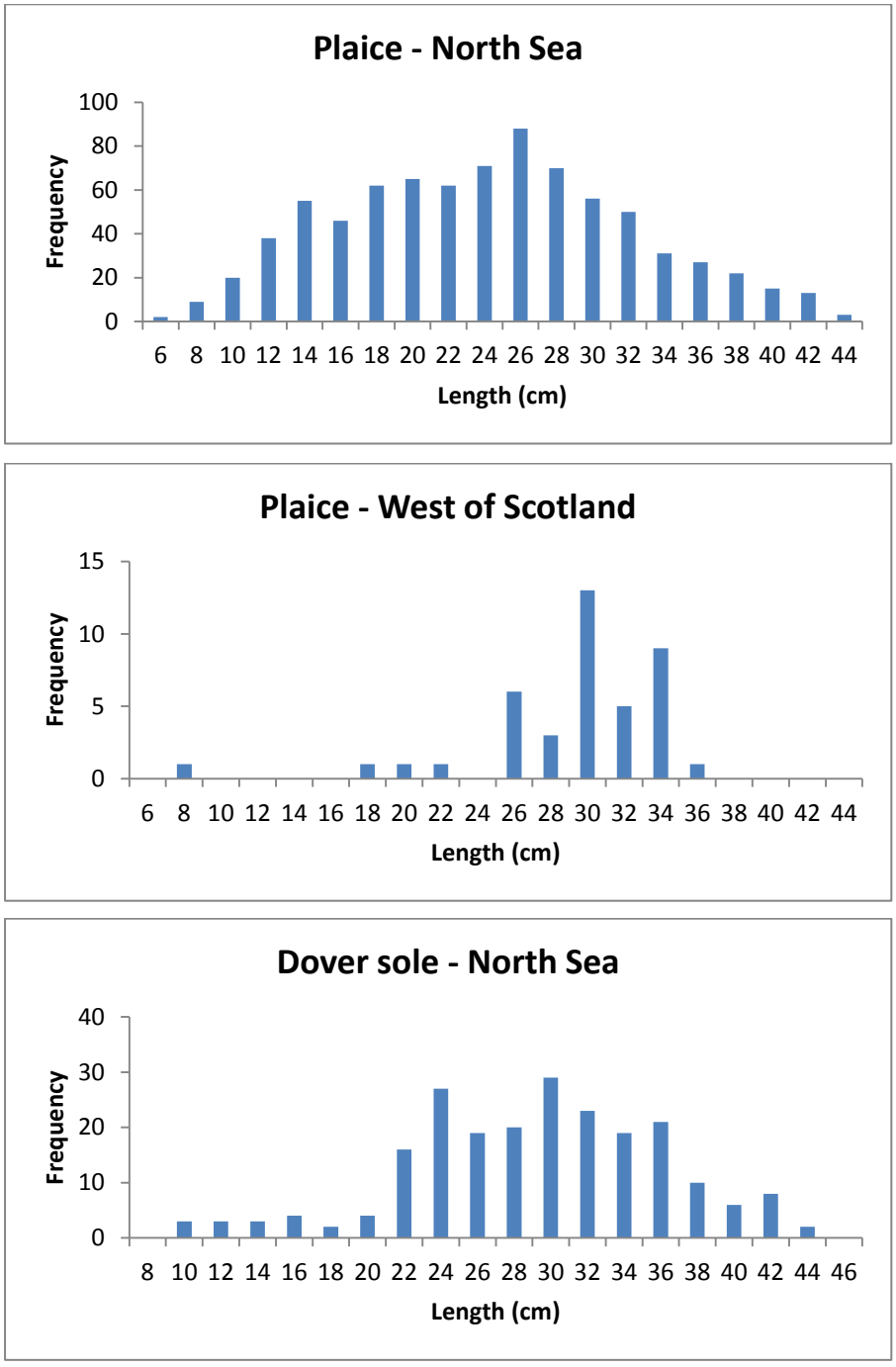


Figure 6: Estimated length frequencies of lemon sole and goby consumed by grey seals in 2010/11.

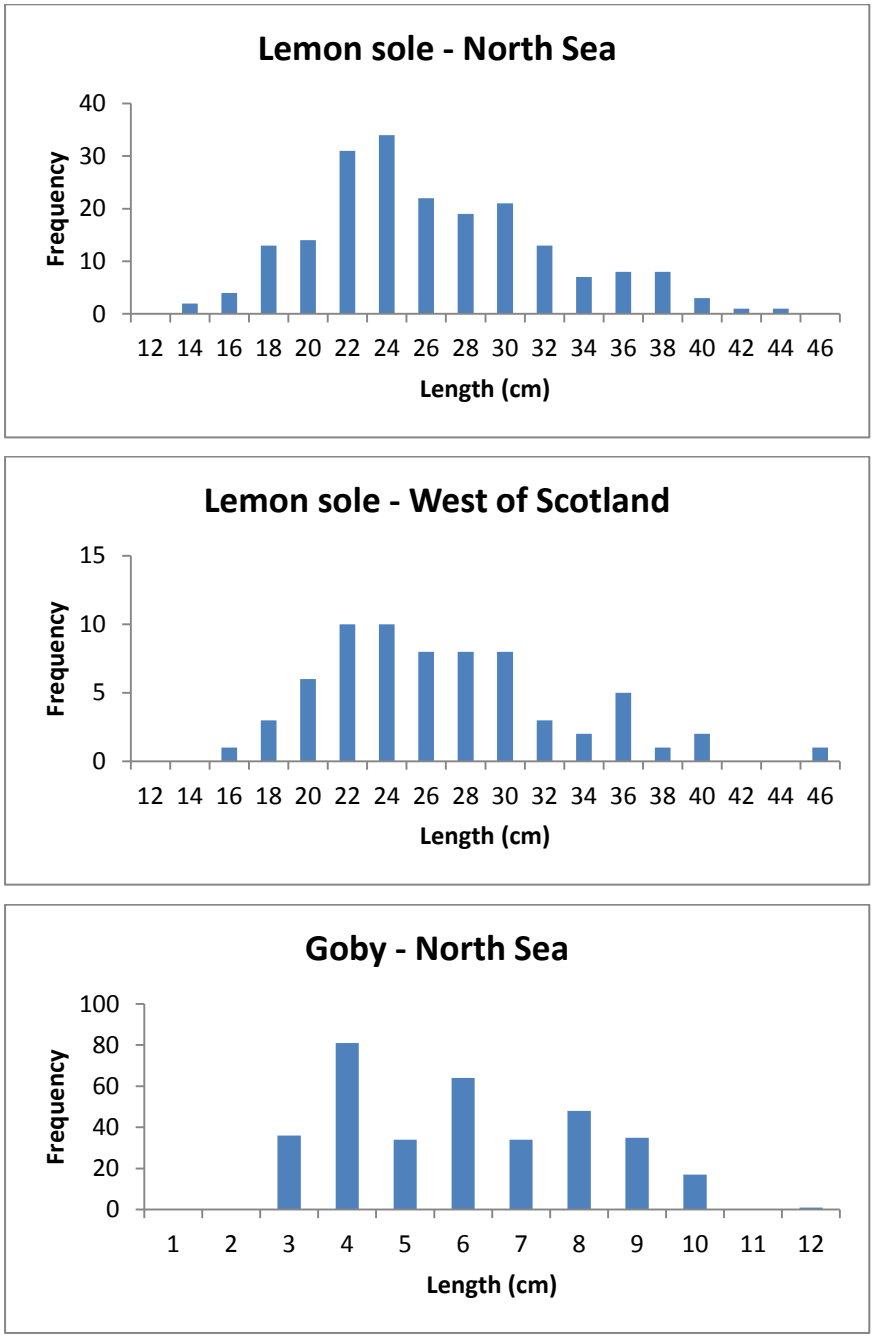
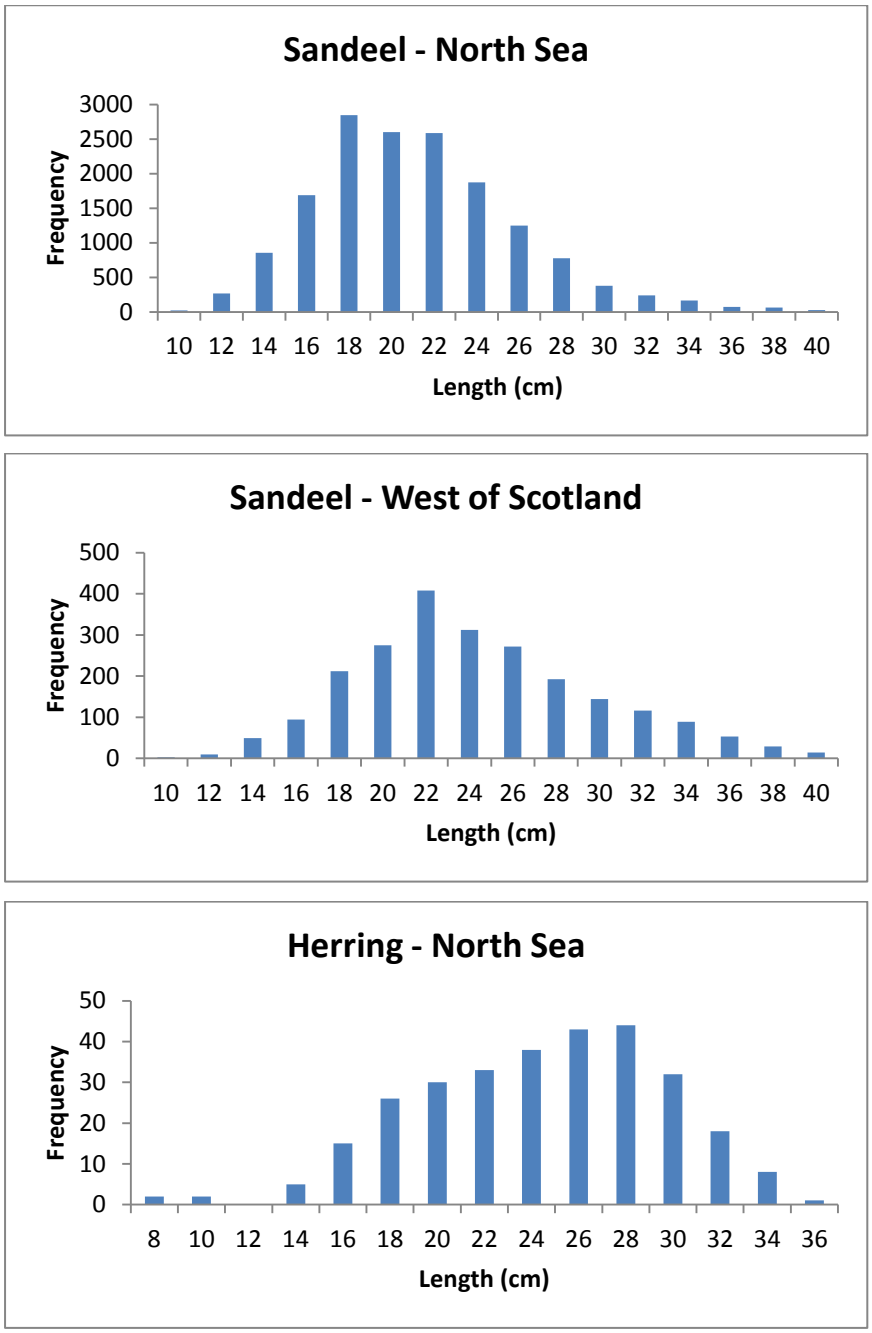


Figure 7: Estimated length frequencies of sandeel and herring consumed by grey seals in 2010/11. Minimum landing size is 20cm for herring.



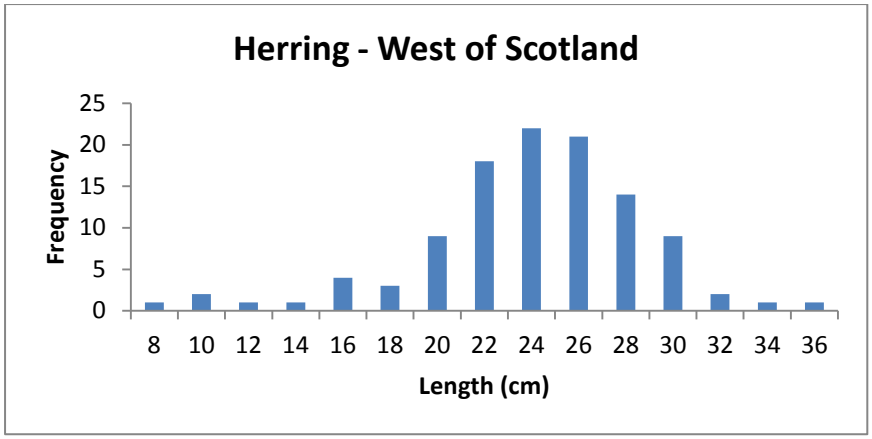
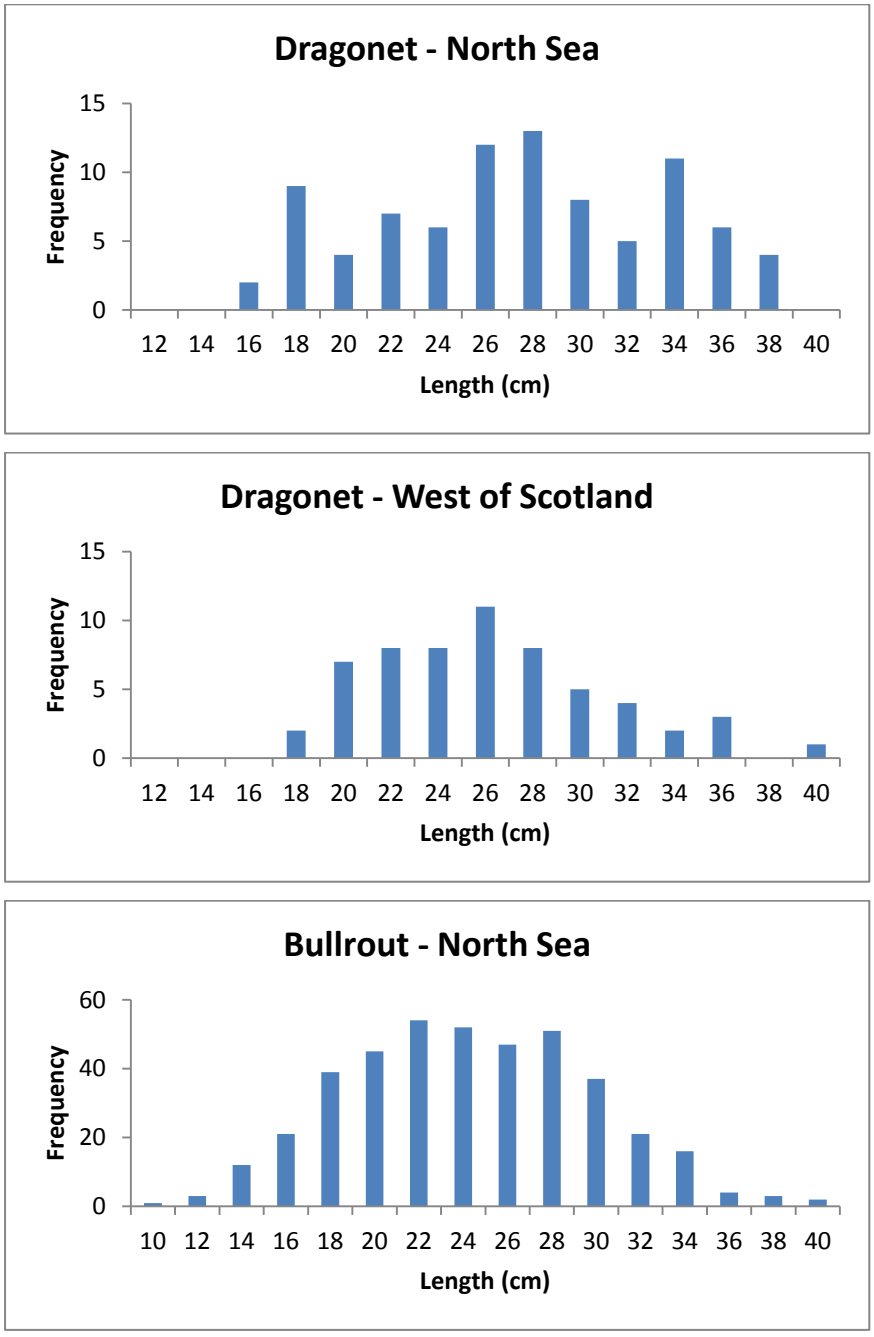
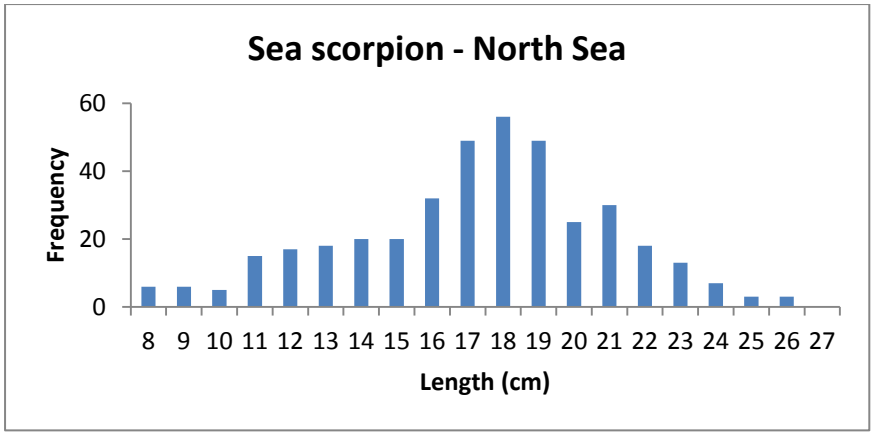

Herring - West of Scotland
Frequency
25
20
15
10
5
0
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
Length (cm)

Figure 8: Estimated length frequencies of dragonet, bullrout and sea scorpion consumed by grey seals in 2010/11.




Sea scorpion - North Sea
Frequency
60
40
20
0
8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27
Length (cm)