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Harbour Seal Diet Composition and Diversity

Lindsay Wilson and Philip Hammond

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

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1 Executive Summary

Previous studies of harbour seal diet around Scotland and elsewhere in Britain and Ireland have described diet composition at small spatial scales. However, these studies have been patchy in time and space, and the most recent results are from the early 2000s. In addition, declines in harbour seal numbers have been observed since 2000 in Shetland, Orkney and eastern Scotland. Reduced availability of prey is one potential contributory cause of these declines. Comparison of diet among regions that exhibit different population trajectories may shed some light on why harbour seals are declining in some parts of Scotland but not others.

The objective of this study was to provide seasonal and regional estimates of harbour seal diet composition and regional estimates of prey consumption, and to investigate how harbour seal diet (composition and/or diversity) relates to the different population trajectories observed around Scotland.

Harbour 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 SMRU studies of seal diet. 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. Sampling variability was estimated using non-parametric and parametric bootstrap resampling methods. Diet diversity was estimated for each region within a season using estimates of prey species richness and the relative abundance of prey species (species evenness). Standard molecular methods were used to ascertain the sex of the seal corresponding to each scat. A total of 1,976 harbour seal scats containing hard prey remains were processed, yielding 65,534 otoliths and beaks.

In the Outer Hebrides, harbour seal diet was approximately evenly split between *Trisopterus* species, pelagic fish, large gadids, scorpion fish, and sandeel. In the Inner Hebrides, large gadids were the main prey; other important species were *Trisopterus* species and pelagic fish. Sandeel contributed little to the diet along the west coast of Scotland. In Orkney, sandeel dominated the diet in summer and spring. Large gadids were important prey in all seasons. Pelagic prey were important in autumn. In Shetland, the diet comprised primarily pelagic prey, large gadids and sandeel.

In south east Scotland the diet comprised primarily flatfish (mainly plaice) and also sandeel and large gadids. In the Moray Firth, sandeel strongly dominated the diet in all seasons. In the southern North Sea, there was considerable seasonal variation in diet composition. The diet was dominated in summer by sandy benthic species, flatfish and sandeel; in autumn by flatfish, large gadids and dragonet; in winter by whiting, scorpion fish and sandy benthic prey; and in spring by flatfish and sandy benthic prey.

The large majority of fish consumed by harbour seals were <30 cm in estimated length and the mean size of each species was mostly below the minimum landing size for cod, haddock, whiting and plaice. The effect of harbour seal predation on fish stocks can only be assessed robustly by incorporating seal predation in fish stock assessments. However, mortality rates of the main fish species in the diet of harbour seals are mostly high so predation on the much larger younger age classes of fish is likely to have less of an effect than would predation on much smaller older age classes. If so, this suggests that the interaction between harbour seals and commercial fisheries around Scotland may not be important for most fish species.

In all regions, except the Moray Firth, there were some differences in male and female diet across all seasons. In The Wash and Scottish west coast regions, females ate fewer large gadids than males and made up the difference in percentage contribution with sandy benthic and pelagic fish in The Wash, pelagic fish in the west coast - central region and *Trisopterus* species in the west coast - south region. The diet of male and female harbour seals matched most closely during the summer. This similarity in prey composition of the diet may reflect male seals mirroring the distribution of female seals at this time of year. Overall, across all seasons, species richness and evenness did not vary greatly between the diet of male and female harbour seals; however, a small degree of seasonal variation was observed across the diet of both sexes in The Wash in winter and spring.

Overall, harbour seals were estimated to have consumed 23,710 t (95% confidence interval: 21,900-26,170 t) of prey in the North Sea (ICES Subarea IV) and 29,950 t (95% confidence interval: 26,820-32,980 t) of prey west of Scotland (ICES Division VIa) in the 12 months from April 2010 to March 2011, and a grand total of 53,660 t (95% confidence interval: 50,180-57,400 t).

Overall, no clear consistent pattern emerged to link estimated diet composition of harbour seals with observed population trends. Instead, variation in diet appeared to correspond largely to regional and seasonal differences in prey distribution and abundance. However, there was a pattern between diet diversity and population trend. Prey species richness and evenness were generally lower in Orkney and Shetland, where harbour seals have declined, and higher in the west coast of Scotland and The Wash, southern North Sea, where harbour seals have not declined. This relationship did not hold in the Moray Firth, where the diet was dominated by a single prey type (sandeel).

Sandeel was an important component in harbour seal diet in Shetland, Orkney and the Moray Firth and quite important in southeast Scotland - all regions where populations have shown declines. Sandeel was not an important component of the diet west of Scotland, where populations have remained stable, nor in the southern North Sea, where the population is increasing.

Direct comparison of results with other studies was affected by methodological differences but it was possible to take this into account qualitatively and draw some inferences about

changes in harbour seal diet over time. Combining this with information on estimated sandeel biomass from stock assessments revealed a general pattern regarding the relationship between diet and trends in population size of harbour seals. Where harbour seals have declined (northern and eastern Scotland) sandeel stocks have also declined and, although their contribution to the diet has declined, they remain an important component of the diet. In regions where harbour seals have not declined (west coast of Scotland, southern North Sea), sandeel were and remain unimportant in the diet and, in the southern North Sea, sandeel stocks have increased.

Overall, with the caution that information is incomplete, the diet of harbour seals is less diverse and at least partially reliant on declining sandeel stocks in regions where population declines have been observed, and is more diverse and not reliant on sandeels in regions where population declines have not been observed. A tentative conclusion is that declines in harbour seal abundance in northern regions may be linked to a decline in the abundance of sandeels.

2 Introduction

Harbour seal diet has been studied around Scotland and elsewhere in Britain and Ireland since the 1980s (Pierce *et al.* 1991, Thompson *et al.* 1996, Tollit and Thompson 1996, Tollit *et al*. 1997, Brown and Pierce 1997, 1998, Hall *et al.* 1998, Brown *et al.* 2001, Wilson *et al.* 2002, Pierce and Santos 2003, Sharples *et al.* 2009). These studies have described diet composition at small spatial scales in the Moray Firth, Orkney, Shetland, western Scotland, south east Scotland, Northern Ireland and The Wash, England. Together they show that harbour seals around the British Isles feed on a variety of prey including sandeel, gadids, flatfish, herring, sprat, octopus and squid, and that diet varies seasonally and regionally.

Although these earlier studies provide valuable information, the description of harbour seal diet is patchy in time and space, and the most recent results are from the early 2000s. In addition, methods of analysis have improved and the results of earlier studies are subject to bias that can be accounted for in recent studies. Although the harbour seal is less numerous than the grey seal around Britain (Duck *et al.* 2014, Duck and Morris 2014, Thomas 2014), it is still a major marine predator in Scottish waters and may have some impact on fish populations or itself be impacted by changes in prey availability. The lack of a comprehensive, up to date description of harbour seal diet hinders understanding of its role in the marine ecosystem.

Declines in harbour seal abundance have been observed in Shetland, Orkney eastern Scotland (Lonergan *et al.* 2007, Duck *et al.* 2014, SCOS 2015) but the cause(s) of these declines are unknown (Sea Mammal Research Unit 2012, 2014). Reduced availability of a sufficient quantity or quality of prey is one potential contributory cause of these declines, especially if this had an impact at a critical life history stage. Comparison of diet among regions that exhibit different population trajectories may shed some light on why harbour seals are declining in some parts of Scotland but not others.

In this report the work to address the following objectives is described:

- Estimate harbour seal diet composition in 2010/11, regionally and seasonally;
- Estimate the size of prey consumed by harbour seals, regionally and seasonally;
- Examine if there is sex-specific variation in harbour seal diet;
- Investigate how harbour seal diet relates to the different population trajectories observed around Scotland;
- Estimate harbour seal prey consumption in 2010/11, regionally.

3 Methods

3.1 Fieldwork

Scats were collected in 2010/2011 up to two hours before and after low water (derived from POLTIPS, National Oceanographic Centre, NERC). Scats were placed into separate plastic bags and stored at -20°C. All scats collected were expected to be no more than two weeks old (since the last spring tide).

Scat collections were stratified spatially and temporally and as weather allowed. Collections were distributed spatially in Scotland to match the Scottish Government designated Seal Management Regions (Baxter *et al.* 2011) and also included The Wash in south east England. All ten Special Areas of Conservation for harbour seals were included in the sampling programme. Table 1 lists all haul-out sites from which scats were successfully collected. Samples were collected in: summer (June–August, harbour seal pupping, breeding and early moult), autumn (September–November, harbour seal end of moult and start of the main period of foraging), winter (December–February, period mainly defined by foraging) and spring (March–May, pre-pupping), following Sharples *et al.* (2009). Table 2 shows the numbers of scats containing fish otoliths and or cephalopod beaks collected in each region/season and Table 3 shows the number of otoliths/beaks of each prey species recovered in scats, by region.

Before approaching a haul-out site, the number of harbour seals was counted and any grey seals were identified and counted. Haul-out sites were designated as a single species site if the area contained ≥80% of one species (based on a low misclassification rate of 3% in molecular analyses to identify the species, Matejusová *et al.* 2013, Wilson 2014) or if the seals were spatially segregated at the haul-out site.

Table 1

Haul-out sites where harbour seal scats were successfully collected. WC = west coast of Scotland.

Region	Location	Haul-out site
England	The Wash and north Norfolk coast SAC	Fleethaven
England	The Wash and north Norfolk coast SAC	Kenzie Creek
England	The Wash and north Norfolk coast SAC	Evans Creek
England	The Wash and north Norfolk coast SAC	Daseley's Sand
England	The Wash and north Norfolk coast SAC	Hull Sand
England	The Wash and north Norfolk coast SAC	Pandora Sand
England	The Wash and north Norfolk coast SAC	Seal Sand
England	The Wash and north Norfolk coast SAC	Thief Sand
England	The Wash and north Norfolk coast SAC	Styleman's Middle
SE Scotland	Firth of Tay and Eden Estuary SAC	Abertay sands
SE Scotland	Firth of Tay and Eden Estuary SAC	Naughtons Bank
SE Scotland	Firth of Tay and Eden Estuary SAC	River Eden
SE Scotland	Firth of Forth	Seafield Tower, Kirkcaldy
Moray Firth	Moray Firth	Ardesier
Moray Firth	Moray Firth	Findhorn
Moray Firth	Dornoch Firth and Morrich More SAC	Whiteness
Moray Firth	Dornoch Firth and Morrich More SAC	Gizzen Briggs
Moray Firth	Beauly Firth	Torrgorn Bank
Moray Firth	Cromarty Firth	Bridge
Orkney	Scapa Flow	Barrel of Butter
Orkney	Eynhallow sound	Burgar Farm
Orkney	Eynhallow sound	Eynhallow
Orkney	Finstown Bay	Damsay
Orkney	Westray	Papa Westray, Holm of Papay
Orkney	Westray	Papa Westray, Weelie's Taing
Orkney	Sanday SAC	Holms of Ire
Orkney	Shapinsay	Shapinsay, Broch
Orkney	Scapa Flow	Switha
Orkney	Westray	Skerry of Wastbist
Shetland	Lunning sound	Lunning Sound Islands
Shetland	Mousa SAC	Mousa
Shetland	SE Shetland	Voe of Sound
Shetland	South Nesting	Skudill's Wick
Shetland	West mainland	Bixter voe
Shetland	West mainland	Vementry
Shetland	Yell Sound Coast SAC	Lunna Ness, Sand Skerry
Shetland	Yell Sound	Lunna Ness, Little Holm
Outer Hebrides	Stornoway	Broad Bay, Sgeir Leathann
Outer Hebrides	South Uist	Loch Aineort
Outer Hebrides	Benbecula	Flodaigh
Outer Hebrides	Harris east	East Loch Tarbert

Outer Hebrides	Loch Maddy	Loch Maddy
WC - north	Summer Isles	Sgeirean Glasa
WC - north	Summer Isles	Carn naan Sgier
WC - north	Oldany Islands	Oldanay Islands
WC - north	Loch Glen Coul Islands	Loch Glen Coul Islands
WC - central	Inner Sound	Crowlin Islands
WC - central	Ascrib, Isay and Dunvegan SAC	Ascrib Islands
WC - central	Ascrib, Isay and Dunvegan SAC	Dunvegan Castle Islands
WC - central	Ascrib, Isay and Dunvegan SAC	Dunvegan west Islands
WC - central	Loch Dunvegan	Loch Bay, Mingay
WC - central	Loch Dunvegan	Loch Bay, Sgeir nam Biast
WC - central	Plock of Kyle	Skye Bridge skerries
WC - south	Ardfern	Eiean na Cillie
WC - south	Gigha	Cara Reef
WC - south	Gigha	Caolas Gigalum
WC - south	South-East Islay Skerries SAC	Plod Sgeirean
WC - south	South-East Islay Skerries SAC	Loch a'Chnuic
WC - south	Jura	Lowlandsman Bay
WC - south	Jura	West Loch Tarbert
WC - south	Eileanan agus Sgeiran Lios mór SAC	Eilean Dubh skerry

Table 2

Number of harbour seal scat samples (containing hard parts that were processed) collected by season in 2010/11 and the total number of hard parts (fish otoliths and cephalopod beaks) recovered. WC = west coast of Scotland.

Region	Season	Number of scats	Total otoliths/beaks	Measured otoliths/beaks
The Wash	Summer	122	3,534	2,473
The Wash	Autumn	81	1,371	1,178
The Wash	Winter	62	1,419	741
The Wash	Spring	23	614	317
SE Scotland	Summer	13	1,821	610
SE Scotland	Autumn	13	1,108	590
SE Scotland	Winter	4	3,100	829
SE Scotland	Spring	9	197	106
Moray Firth	Summer	89	10,509	3,752
Moray Firth	Autumn	21	2,078	764
Moray Firth	Winter	52	1,406	742
Moray Firth	Spring	103	6,528	2,700
Orkney	Summer	117	4,142	2,391
Orkney	Autumn	113	1,377	914
Orkney	Winter	4	152	72
Orkney	Spring	23	790	422
Shetland	Summer	47	1,654	860
Shetland	Autumn	111	2,622	1,642
Shetland	Winter	0		
Shetland	Spring	28	491	373
Outer Hebrides	Summer	99	1,584	1,180
Outer Hebrides	Autumn	7	81	81
Outer Hebrides	Winter	6	718	304
Outer Hebrides	Spring	0		
WC - north	Summer	93	3,095	2,530
WC - north	Autumn	12	115	106
WC - north	Winter	1	35	35
WC - north	Spring	43	468	420
WC - central	Summer	82	1,963	1,563
WC - central	Autumn	139	2,693	1,790
WC - central	Winter	71	2,399	1,520
WC - central	Spring	80	656	603
WC - south	Summer	83	3,421	2,783
WC - south	Autumn	134	1,971	1,565
WC - south	Winter	34	398	368
WC - south	Spring	57	1,024	905

Table 3: Number of fish otoliths and cephalopod beaks recovered from harbour seal scats in 2010/11. WC = west coast of Scotland.

Prey group	Prey species	The Wash	SE Scotland	Moray Firth	Orkney	Shetland	Outer Hebrides	WC - north	WC - central	WC - south	TOTAL
	Whiting	637	641	55	8	13	38	502	868	1,659	4,421
	Unid. gadid	3	8	37	138	289	45	164	219	601	1,504
	Blue whiting	0	0	0	0	1	0	162	767	290	1,220
	Cod	21	27	82	22	672	33	78	58	125	1,118
	Saithe	0	6	51	692	169	8	55	60	31	1,072
	Haddock	0	11	18	2	50	14	38	118	711	962
	Silvery pout	0	0	0	0	0	0	0	123	0	123
	Rockling	0	0	2	3	21	2	7	11	44	90
	Ling	0	0	0	15	16	2	22	16	9	80
	Hake	0	0	1	1	0	0	0	15	0	17
	3-bearded rockling	0	0	0	1	0	1	2	0	10	14
	Saithe or Pollock	0	0	0	0	0	0	3	6	0	9
	4-bearded rockling	0	0	0	0	1	0	0	2	1	4
	Forkbeard	0	0	0	2	0	0	0	1	0	3
	Pollock	0	0	0	0	0	0	0	2	0	2
	Tadpole fish	0	0	0	2	0	0	0	0	0	2
	5-bearded rockling	1	0	0	0	0	0	0	0	0	1
	Sea snail	0	0	0	0	0	1	0	0	0	1
Gadid	**TOTAL**	**662**	**693**	**246**	**886**	**1232**	**144**	**1,033**	**2,266**	**3,481**	**10,643**
	Norway pout	0	0	1	569	3	999	1,043	1,452	795	4,862
	Poor cod	2	0	13	300	128	258	502	1,934	1,284	4,421
	Unid. *Trisopterus*	0	0	0	98	45	54	401	214	174	986
	Norway pout or Poor cod	0	0	0	0	0	19	442	169	1	631
	Pout whiting	27	0	0	0	0	0	1	0	4	32
Trisopterus	**TOTAL**	**29**	**0**	**14**	**967**	**176**	**1,330**	**2,389**	**3,769**	**2,258**	**10,932**
Sandeel	**TOTAL sandeel**	**829**	**1,261**	**18,311**	**2,507**	**4,506**	**754**	**115**	**672**	**137**	**29,092**

Prey group	Prey species	The Wash	SE Scotland	Moray Firth	Orkney	Shetland	Outer Hebrides	WC - north	WC - central	WC - south	TOTAL
	Plaice	770	1,022	801	20	60	8	8	31	45	2,765
	Unid. flatfish	307	359	434	3	35	2	1	16	13	1,170
	Dab	279	186	359	5	63	0	0	20	18	930
	Flounder	41	23	67	0	12	0	0	0	0	143
	Dover sole	122	0	0	0	0	0	0	1	2	125
	Lemon sole	38	3	2	5	3	0	1	13	9	74
	Witch	0	0	0	0	0	0	1	9	64	74
	Long rough dab	0	2	9	0	1	0	0	24	18	54
	Flounder or Plaice	8	0	11	0	0	0	0	0	0	19
	Thickback sole	0	0	0	0	0	0	0	8	6	14
	Brill	10	0	1	0	0	0	0	0	0	11
	Norwegian topknot	0	0	0	0	0	0	5	4	2	11
	Unid. sole	0	0	0	0	0	0	0	4	3	7
	Scaldfish	0	0	2	0	0	0	0	0	1	3
	Megrim	0	0	1	0	0	0	0	1	0	2
	Topknot	0	0	0	0	1	0	0	0	0	1
Flatfish	**TOTAL**	**1,575**	**1,595**	**1,687**	**33**	**175**	**10**	**16**	**131**	**181**	**5,403**
	Goby	2,898	2,522	18	4	9	0	0	8	20	5,479
	Dragonet	684	10	4	131	51	28	3	346	334	1,591
	Butterfish	1	0	0	0	14	0	0	0	10	25
Sandy benthic	**TOTAL**	**3,583**	**2532**	**22**	**135**	**74**	**28**	**3**	**354**	**364**	**7,095**
	Sea Scorpion	20	0	0	0	41	0	0	2	0	63
	Bullrout	22	1	25	0	6	0	0	1	5	60
	Unid. Cottidae	2	0	0	0	2	16	0	36	1	57
	Hooknose	7	0	0	0	2	0	1	0	2	12
	Gurnard	0	0	0	0	0	0	0	3	4	7
	Grey gurnard	0	0	0	0	0	0	0	6	0	6
Scorpion fish	**TOTAL**	**51**	**1**	**25**	**0**	**51**	**16**	**1**	**48**	**12**	**205**

Prey group	Prey species	The Wash	SE Scotland	Moray Firth	Orkney	Shetland	Outer Hebrides	WC - north	WC - central	WC - south	TOTAL
	Herring	18	1	6	160	189	19	75	180	237	885
	Sprat	106	96	168	1	0	0	0	0	1	372
	Mackerel	0	3	2	28	34	23	31	198	50	369
	Horse mackerel	1	0	0	0	1	22	18	61	5	108
	Argentine	0	0	0	1	0	0	7	8	15	31
	Smelt	13	0	0	0	0	0	0	0	0	13
Pelagic	**TOTAL**	**138**	**100**	**176**	**190**	**224**	**64**	**131**	**447**	**308**	**1,778**
	Unid. Salmonid	0	1	4	0	0	0	0	0	2	7
	Sea trout	0	2	0	0	0	0	1	0	0	3
Salmonid	**TOTAL**	**0**	**3**	**4**	**0**	**0**	**0**	**1**	**0**	**2**	**10**
	Loligo	5	34	24	1	2	0	9	4	3	82
	Eledone	2	0	0	3	4	31	5	8	7	60
	Sepiolids	11	1	0	1	2	1	7	4	23	50
	Alloteuthis species	2	0	0	0	0	0	0	0	0	2
Cephalopod	**TOTAL**	**20**	**35**	**24**	**5**	**8**	**32**	**21**	**16**	**33**	**194**
	Wrasse	0	0	0	1	1	3	0	1	17	23
	Unknown Species	8	1	0	4	0	0	0	0	0	13
	Unid. roundfish	13	0	2	1	3	2	2	3	1	27
	Snake blenny	0	2	0	0	0	0	0	0	0	2
	Lesser weever	25	0	1	0	0	0	0	0	0	26
	Garfish	4	0	0	37	2	0	0	0	0	43
	Eelpout	0	3	9	1	4	0	1	0	14	32
	Cuckoo wrasse	0	0	0	0	2	0	0	4	1	7
	Conger eel	0	0	0	0	0	0	0	0	1	1
	Bass	1	0	0	0	0	0	0	0	0	1
	Ballan wrasse	0	0	0	0	3	0	0	0	4	7
Other	**TOTAL**	**51**	**6**	**12**	**44**	**15**	**5**	**3**	**8**	**38**	**182**
TOTAL		**6,938**	**6,226**	**20,521**	**4,767**	**6,461**	**2,383**	**3,713**	**7,711**	**6,814**	**65,534**

3.2 Laboratory Analysis

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. Scats were subsequently machine washed (Orr *et al.* 2004), following the protocol developed by S. Brasseur (pers. comm.); that is, on 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 an individual scat collection, otoliths and beaks were extracted using running water through a nest of sieves to avoid damage to prey hard remains; mesh sizes 1 mm, 600 µm, 335 µm and 250 µm. The presence of other possible prey remains (*e.g.* feathers and crustacean carapaces) was noted.

Otoliths were stored dry and identified by John Watkins to the lowest possible taxonomic group based on morphological criteria using a reference collection and identification guides (Härkönen 1986, Leopold *et al.* 2001). Beaks were stored in 70% IMS and identified to species by Caya Sievers using a reference collection and identification guide (Clarke 1986). Where prey remains could not be identified to species, they were recorded at a higher level (*e.g.* sandeel, unidentified gadid).

Otolith lengths and widths and cephalopod lower rostral or lower hood lengths were measured to the nearest 0.01 mm using digital callipers (Mitutoyo) under binocular microscopes. Broken otoliths and beaks were counted and measured only if the widest/longest part of the otolith, or the lower beak, was unbroken. Fragments of otoliths or beaks which were not large enough to be measured were not counted or measured to avoid misidentification of species and double counting.

All counted otoliths and beaks were measured unless a large number of a prey species occurred in a scat. In such cases, 30 otoliths were randomly chosen with respect to size 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.

The degree by which each measured otolith was digested was recorded after examination of individual morphological features (Tollit *et al.* 1997, Leopold *et al.* 2001). Four grades of digestion were allocated; grade 1 - pristine, grade 2 - moderately digested, grade 3 - considerably digested, and grade 4 - severely digested (Wilson *et al.* 2013, Wilson 2014). The amount by which cephalopod beaks had been digested was not classified.

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).

Estimation of harbour seal diet composition generally followed the methods used in previous assessments of grey seal diet by SMRU. Measurements of the size of otoliths/beaks recovered from scats were corrected for partial digestion and used to estimate the weight of prey ingested, values were summed over species, corrected for complete digestion, and expressed as percentages of the diet by weight (Prime and Hammond 1987, 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).

Measurements of partially digested otolith/beak size were converted to estimates of undigested otolith/beak size using experimentally derived grade-specific digestion coefficients (Tollit *et al.* 1997, Wilson *et al.* 2013, Wilson 2014). For each prey species (or higher taxon) the preferred measurement (otolith length or width, or lower rostral or lower hood length) was determined based on the availability of experimental data, the precision of the estimated digestion coefficients (Tollit *et al.* 1997, Wilson *et al.* 2013, Wilson 2014), the measurement available from recovered hard parts and the availability of regression equations to estimate prey size. Where species specific correction factors were not available, group-specific values were used (e.g. gadids, flatfish) or values from prey species with otoliths of similar size and robustness (Härkönen 1986) were applied. The use of values from other species only occurred for prey species that were minor components of the diet.

For some prey species there was no suitable substitution and general “round fish” digestion coefficients were used. For dragonet (*Callionymus lyra*) and Cottidae species, digestion coefficients (DCs) were only available for grey seals (Grellier and Hammond 2006). Species-on-species comparison showed that harbour seal digestion coefficients were generally smaller than grey seal DCs (by 8.3%, on average). Grey seal DCs for dragonet and short-spined sea scorpion (bullrout) were, therefore, multiplied by 0.917 to use for harbour seals. For herring, estimated fish size was sensitive to the choice of DC. Based on a comparison of available DCs, the species-specific DC generated by Tollit *et al.* (1997) provided the most realistic estimates of fish size and was, therefore, used in analysis.

Estimates of fish/cephalopod weight were derived from the estimates of undigested otolith/beak size using allometric equations (Clarke 1986, Härkönen 1986, Leopold *et al.* 2001, Santos *et al.* 2001, GJ Pierce and MB Santos pers. comm.). Where no equations were available for prey species, equations for the closest matching species were used; these species were all minor prey.

For scats in which 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 weight of that species over all scats was used.

To account for species-specific differences in complete digestion, the weight estimated for each prey species was adjusted using experimentally derived number correction factors (Wilson *et al.* 2013, Wilson 2014). Where no experimental data were available, group-specific values (*e.g.* gadids, flatfish) or the closest matching species were used.

3.4 Estimation of Prey Consumption

To estimate the amount of prey consumed by harbour 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 harbour seals in each region/season was calculated as the product of:

- the estimated average daily energy requirement of 4,680 Kcals (Härkönen and Heide-Jørgensen 1991);
- the estimated number of seals in the region: Shetland = 4,221; Orkney = 3,901; Moray Firth = 1,667; Southeast Scotland = 411; Southern North Sea = 5,119; Outer Hebrides = 2,506; WC North = 961; WC Central = 5,561; WC South = 8,215 (data from Duck *et al.* 2014);
- 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).

3.5 Estimation of Variability

Precision of estimates of diet composition was estimated 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 1000 times. Measurement error was estimated using parametric resampling of the coefficients describing the relationships used to obtain estimates of diet composition 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; and (c) accounting for complete digestion of otoliths/beaks using estimated number correction factors.

Estimates of the variability associated with experimentally derived estimates of digestion coefficients and number correction factors were taken from Wilson *et al.* (2013). 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 cephalopod beak size - cephalopod weight.

For estimates of diet composition within each region/season, 95% confidence limits were estimated as the 2.5%-ile and 97.5%-ile of the bootstrapped distributions.

3.6 Diet Diversity

Diet diversity was estimated for each region within a season using estimates of species richness and the relative abundance of species (species evenness). Species Richness (S) was calculated as the total number of species identified in the sample and evenness was measured using Pielou's evenness index (PIE). PIE provides a measure of how different the abundances of the species in a community are from each other (Smith and Wilson 1996). Evenness is highest when species abundance is evenly spread and not dominated by one or a few species with high abundance. Rarefaction to a common sampling effort (number of scats collected) was used to adjust for differences in sampling intensity, allowing meaningful standardisation and comparison of datasets (Simberloff 1978, Gotelli and Colwell 2001, 2011). This incurs loss of information but this is necessary to allow valid comparison.

To generate species richness from a rarefied (reduced) sample of scats, this number of scats was randomly re-sampled multiple times from the total number of scats and the number of species determined. The data were rarefied to the minimum number of scats across regions within a season. Note that this means that species richness can only be compared across regions within seasons not across seasons.

PIE was calculated as $J = \frac{H'}{log(S)}$ where *H'* is the Shannon-Weiner diversity index and *S* is the rarefied total number of species in a sample. The value of *J* ranges from 0 to 1, with larger values representing more even distributions in abundance among species.

3.7 Length of fish consumed

Distributions of fish length were generated for those species making major contributions to the diet. Fish lengths were estimated using equations relating otolith width/ length to fish length from Leopold *et al.* (2001) from otolith measurements corrected for partial digestion.

3.8 Sex-specific variation in the diet of harbour seals

Regions (The Wash, Moray Firth, West coast - central and West coast - south) were selected *post-hoc* for inclusion in the analysis of sex-specific diet, based on the number of scats collected per region/season. The method of Matejusová *et al.* (2013) was used to ascertain the sex of the seals. Two Taqman assays targeting homologs of the ZFP on the X and Y chromosomes (ZFX and ZFY, respectively) and an additional assay amplifying the male-specific SRY gene were applied; sex determination was based on the outcome of each assay. Scats where the SRY and ZFY genes failed to amplify but the species of seal was successfully determined were subsequently classed as female based on the assumption that the failure of both SRY and ZFY to amplify indicates a female seal but that the X chromosome assay failed due its relatively poor amplification efficiency and the highly degraded nature of DNA from scats. Molecular analysis was conducted by Iveta Matejusova and Judy Simons (Marine Scotland Science), and by Tom Ashton (Xelect Ltd, University of St Andrews).

A total of 1,048 (73.2%) sex confirmed scats contained otoliths and/or beaks (Table 4). The highest proportions of scats that did not contain otoliths and/or beaks were from The Wash (32.3%).

Table 4

Summary of the number of male/female scats containing otoliths/beaks and the percentage of sex confirmed scats that contained otoliths/beaks.

	Scats			Percentage		
	M	**F**	**TOTAL**	**M**	**F**	**TOTAL**
The Wash						
Summer	81	67	148	81.8	72.8	77.5
Autumn	96	48	144	75.0	72.7	74.2
Winter	43	19	62	50.6	47.5	49.6
Spring	18	47	65	46.2	67.1	59.6
TOTAL	238	181	419	67.8	67.5	67.7
Moray Firth						
Summer	31	40	71	81.6	81.6	81.6
Autumn/ Winter	19	33	52	76.0	71.7	73.2
Spring	36	40	76	83.7	70.2	76.0
TOTAL	86	113	199	81.1	74.3	77.1
West coast - central						
Summer	22	10	32	84.6	83.3	84.2
Autumn	102	10	112	73.4	71.4	73.2
Winter	35	5	40	79.5	83.3	80.0
Spring	42	2	44	82.4	50.0	80.0
TOTAL	201	27	228	77.3	75.0	77.0
West coast - south						
Summer	34	7	41	94.4	70.0	89.1
Autumn	66	13	79	83.5	76.5	82.3
Winter	8	7	15	29.6	100.0	44.1
Spring	59	8	67	81.9	72.7	80.7
TOTAL	167	35	202	78.0	77.8	78.0

4 Results

4.1 Diet Composition

The diet of harbour seals expressed as a percentage by weight of each prey species is given in Table 5 and summarised by prey group (gadids, flatfish, etc.) in Table 6; 95% confidence intervals are given in Appendices 2 and 3.

North Sea: In the Wash, England, seasonal variation was evident in diet composition. The diet was dominated in the summer by sandy benthic species (primarily dragonet), flatfish and sandeel, in autumn by flatfish, large gadids (mainly whiting) and dragonet, in winter by whiting, scorpion fish (bullrout and sea scorpion and sandy benthic prey (dragonet and gobies) and in spring by flatfish (mainly Dover sole) and sandy benthic prey (dragonet and gobies). Diet composition in south east Scotland, presented across all seasons due to small sample sizes, was dominated by flatfish (mainly plaice) with additional major contributions of

sandeel and large gadids. In the Moray Firth, sandeel dominated the diet in all seasons; in summer, when sandeel contribution to the diet was lowest, flatfish were important prey.

Northern Isles: In Orkney, sandeel dominated the diet in summer and spring. Cod were also important prey in summer and saithe in spring. In autumn, pelagic and gadid fish (mainly herring and cod) dominated the diet. In Shetland, pelagic prey and sandeel dominated the diet in summer, in autumn, sandeel, pelagic fish and saithe were important and, in spring, pelagic fish (mainly herring), large gadids (mainly saithe and rockling) and dragonet were dominant prey. Winter diet is not described due to small sample size.

West coast: Due to small sample sizes, only summer diet is described for the Outer Hebrides, where diet was approximately evenly split between *Trisopterus* species, large gadids, scorpion fish, sandeel and pelagic fish. In the Inner Hebrides, west coast - north region, large gadids (mainly cod in summer and ling in spring), pelagic fish and *Trisopterus* species were major components of diet in both spring and summer. Large gadid fish dominated the diet of west coast - central harbour seals in all seasons except autumn, when pelagic prey dominated. In summer, winter and spring, blue whiting was the dominant large gadid in the diet. In autumn, sandy benthic prey were also important. Pelagic fish were also important in the diet in spring. Sandeel contributed very little to the diet of west coast - south harbour seals and generally the large gadid contribution was high. The diet was dominated in summer by whiting and haddock, in autumn by haddock and herring and in winter and spring by large gadids (cod, whiting, saithe and haddock in winter and haddock and cod in spring).

The width of estimated confidence intervals for each species or prey group (Appendices 2 and 3) 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 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 3).

4.2 Diversity of Prey

Overall, species richness was consistently highest in the west coast - central and south regions in all seasons and species evenness was also consistently highest west of Scotland in all seasons (Table 7). Species evenness, but not richness, was also high in The Wash in most seasons. These are regions where harbour seal populations are stable or increasing (Lonergan *et al.* 2007, Duck *et al.* 2014). In contrast, species evenness was lower in Orkney in all seasons for which data were available and in Shetland in summer and autumn (Table 7). These are regions where harbour seal populations are decreasing (Lonergan *et al.* 2007, Duck *et al.* 2014). The Moray Firth diet was highly specialised as illustrated by a lower species evenness than in other regions in all seasons.

4.3 Size of Prey Consumed

Fish length-frequency distributions pooled over all seasons and regions were created for those species that were major contributors to the diet (Appendix 1). The lengths are estimated and thus subject to error, although using grade specific digestion coefficients should help to minimise this error. In the length-frequency plots the errors are mostly apparent in the tails of the distributions, the extent of which should not therefore be over-interpreted. The distributions of prey lengths show that seals mainly consumed fish < 30 cm. The mean sizes of species/prey groups were as follows: large gadids 17.4-24.3 cm, *Trisopterus* species 12.4-14.0 cm, flatfish 14.2-17.4 cm, pelagic fish 26.6-32.6 cm, sandeel 15.5 cm and dragonet 19.2 cm.

Table 5

Harbour seal diet composition, expressed as percentage of the diet by weight for the main prey species, for each region and season.

A) The Wash

Species	Summer	Autumn	Winter	Spring
Whiting	1.5	30.3	22.5	2.2
Cod	2.4	0.2	4.1	0.0
Sandeel	22.2	6.6	6.0	3.4
Dover sole	6.0	9.6	1.9	34.7
Plaice	9.0	10.3	2.1	0.6
Lemon sole	1.9	5.9	6.6	0.0
Unid. flatfish	2.3	5.2	0.7	0.2
Dab	5.0	4.0	0.7	0.7
Flounder	3.7	1.1	0.0	0.0
Dragonet	38.8	19.1	8.8	29.7
Goby	4.2	0.6	6.3	16.3
Bullrout	0.0	2.0	14.2	10.2
Sea scorpion	0.1	0.3	5.6	0.0
Sprat	0.0	0.0	7.5	1.8
Herring	0.0	0.1	5.5	0.0
Loligo	0.0	1.4	3.8	0.0

B) Southeast Scotland

Species	All Seasons
Whiting	8.3
Cod	3.8
Sandeel	18.4
Plaice	28.1
Dab	7.3
Flounder	5.4
Unid. flatfish	3.8
Goby	2.2
Sprat	4.6
Mackerel	3.6
Loligo	8.4

C) Moray Firth

Species	Summer	Autumn	Winter	Spring
Saithe	0.2	1.5	5.6	1.1
Sandeel	58.3	75.6	69.3	85.5
Dab	15.3	1.4	2.8	0.5
Plaice	11.0	1.8	0.9	0.6
Flounder	1.1	0.9	5.9	6.3
Unid. flatfish	3.4	0.6	1.4	1.8
Bullrout	3.3	6.5	0.0	0.3
Sprat	0.0	0.0	8.9	2.7
Unid. Salmonid	0.7	5.8	0.0	0.0
Loligo	2.4	1.0	0.0	0.0

D) Orkney

Species	Summer	Autumn	Spring
Cod	23.0	29.7	4.1
Saithe	2.6	2.3	24.2
Haddock	0.7	3.8	0.5
Ling	2.7	3.4	0.0
Sandeel	50.8	15.2	62.0
Dab	1.4	4.3	0.0
Plaice	2.5	1.2	0.0
Flounder	2.3	0.0	0.0
Dragonet	1.2	3.4	0.0
Sea scorpion	2.4	0.1	0.0
Herring	3.7	23.3	0.6
Mackerel	0.9	8.4	2.3

E) Shetland

Species	Summer	Autumn	Spring
Saithe	4.3	23.3	15.0
Ling	13.0	0.8	2.0
Rockling	0.9	0.0	10.1
3-bearded rockling	0.0	0.0	2.6
Norway pout	8.5	0.5	4.8
Poor cod	1.8	5.4	0.8
Sandeel	36.0	31.5	6.8
Lemon sole	0.0	2.9	0.0
Plaice	2.2	0.2	0.0
Dragonet	0.0	0.9	23.9
Herring	30.2	9.1	29.4
Mackerel	0.8	10.9	2.3
Garfish	0.0	9.9	0.0

F) Outer Hebrides

Species	Summer
Rockling	3.9
Cod	3.6
Ling	2.6
Whiting	2.2
Norway pout	19.8
Poor cod	4.2
Sandeel	13.1
Dragonet	2.8
Unid. Cottidae	16.2
Mackerel	12.6
Herring	4.8
Horse mackerel	2.8
Eledone	3.8

G) West Coast - north

Species	Summer	Spring
Ling	9.1	16.7
Cod	13.6	5.1
Saithe	9.3	7.8
Whiting	9.1	2.1
Blue whiting	7.3	0.5
Rockling	0.0	5.7
Haddock	1.3	2.0
Norway pout	10.4	16.6
Poor cod	8.9	6.0
Norway pout or Poor cod	2.4	0.0
Sandeel	2.5	10.0
Mackerel	5.9	12.2
Herring	10.8	6.1
Loligo	0.5	5.8

H) West Coast - Central

Species	Summer	Autumn	Winter	Spring
Blue whiting	17.4	0.7	16.6	19.0
Whiting	15.1	1.6	9.2	1.0
Haddock	0.5	2.7	2.0	10.0
Cod	1.8	3.8	4.9	7.9
Ling	1.2	1.6	7.4	3.4
Saithe	0.0	1.9	5.8	7.3
Unid. gadid	4.7	0.5	2.7	1.2
Saithe or Pollock	0.0	0.3	3.3	0.0
Hake	2.3	0.0	1.1	1.0
Poor cod	8.0	3.5	12.5	3.2
Norway pout	10.9	1.6	5.1	1.8
Sandeel	6.0	6.6	4.7	3.8
Dab	0.0	3.4	0.2	0.6
Lemon sole	0.5	0.2	0.0	2.5
Plaice	0.2	2.2	0.0	0.6
Dragonet	0.8	21.2	15.3	0.6
Unid. Cottidae	18.8	1.9	0.0	0.0
Mackerel	5.8	29.7	0.2	26.1
Herring	2.6	9.6	2.3	3.2
Horse mackerel	0.0	4.4	1.4	0.1
Eledone	1.2	0.6	0.0	2.3
Loligo	0.0	0.3	0.4	2.0

I) West Coast - South

Species	Summer	Autumn	Winter	Spring
Haddock	16.3	23.2	13.6	26.8
Whiting	23.7	7.4	19.3	13.7
Cod	4.9	7.0	20.0	22.0
Saithe	1.1	1.1	13.7	3.4
Unid. gadid	7.3	2.2	3.3	5.3
Ling	0.9	2.1	7.0	0.0
Blue whiting	5.0	0.3	0.8	3.5
Rockling	0.2	3.3	0.0	0.1
Poor cod	4.0	5.2	7.3	5.1
Norway pout	4.0	0.1	0.6	3.4
Witch	0.8	1.0	0.0	2.1
Dragonet	12.8	10.5	6.2	1.6
Herring	1.8	19.2	2.5	3.4
Mackerel	10.8	5.8	2.0	4.0

Table 6

Harbour seal diet expressed as the percentage of each prey type in the diet by weight for each region and season.

A) The Wash

Prey type	Summer	Autumn	Winter	Spring
Gadid	3.9	30.5	26.7	2.2
Trisopterus	1.2	0.3	1.3	0.0
Sandeel	22.2	6.6	6.0	3.4
Flatfish	28.4	37.1	13.6	36.2
Sandy benthic	43.3	19.9	15.1	46.0
Scorpion fish	0.3	2.7	19.8	10.2
Pelagic	0.1	0.1	13.7	1.8
Salmonid	0.0	0.0	0.0	0.0
Cephalopod	0.0	2.6	3.8	0.0
Other	0.5	0.2	0.0	0.1

B) Southeast Scotland

Prey type	All seasons
Gadid	14.1
Trisopterus	0.0
Sandeel	18.4
Flatfish	45.1
Sandy benthic	3.4
Scorpion fish	0.8
Pelagic	8.2
Salmonid	0.7
Cephalopod	8.4
Other	0.8

C) Moray Firth

Prey type	Summer	Autumn	Winter	Spring
Gadid	2.4	4.2	8.0	1.6
Trisopterus	0.0	0.0	0.5	0.0
Sandeel	58.3	75.6	69.3	85.5
Flatfish	31.5	4.7	10.9	9.8
Sandy benthic	0.2	0.4	1.6	0.0
Scorpion fish	3.3	6.5	0.0	0.3
Pelagic	1.1	1.2	9.4	2.7
Salmonid	0.7	5.8	0.0	0.0
Cephalopod	2.4	1.0	0.0	0.0
Other	0.0	0.7	0.3	0.1

D) Orkney

Prey type	Summer	Autumn	Spring
Gadid	30.7	40.4	31.7
Trisopterus	0.9	0.2	1.5
Sandeel	50.8	15.2	62.0
Flatfish	7.5	6.3	0.0
Sandy benthic	1.2	3.4	0.5
Scorpion fish	3.4	0.2	0.1
Pelagic	4.8	31.8	2.8
Salmonid	0.0	0.0	0.0
Cephalopod	0.3	1.9	1.0
Other	0.3	0.6	0.2

E) Shetland

Prey type	Summer	Autumn	Spring
Gadid	19.6	27.6	29.9
Trisopterus	10.2	5.9	6.4
Sandeel	36.0	31.5	6.8
Flatfish	2.3	3.9	0.0
Sandy benthic	0.0	0.9	23.9
Scorpion fish	0.0	0.0	0.0
Pelagic	31.2	20.0	31.6
Salmonid	0.0	0.0	0.0
Cephalopod	0.6	0.2	1.3
Other	0.0	10.0	0.1

F) Outer Hebrides

Prey type	Summer
Gadid	17.2
Trisopterus	24.5
Sandeel	13.1
Flatfish	2.0
Sandy benthic	2.8
Scorpion fish	16.2
Pelagic	20.3
Salmonid	0.0
Cephalopod	3.8
Other	0.3

G) West coast - north

Prey type	Summer	Spring
Gadid	52.4	40.7
Trisopterus	22.3	22.7
Sandeel	2.5	10.0
Flatfish	1.5	0.3
Sandy benthic	0.4	0.7
Scorpion fish	0.0	0.0
Pelagic	18.9	19.8
Salmonid	0.3	0.0
Cephalopod	1.8	5.8
Other	0.0	0.0

H) West coast - central

Prey type	Summer	Autumn	Winter	Spring
Gadid	43.2	13.4	53.3	51.1
Trisopterus	19.2	5.4	18.0	5.2
Sandeel	6.0	6.6	4.7	3.8
Flatfish	1.2	7.1	2.2	5.5
Sandy benthic	0.8	21.2	15.3	0.6
Scorpion fish	19.6	1.9	1.9	0.0
Pelagic	8.5	43.6	4.3	29.5
Salmonid	0.0	0.0	0.0	0.0
Cephalopod	1.2	0.9	0.4	4.3
Other	0.3	0.0	0.0	0.0

I) West coast - south

Prey type	Summer	Autumn	Winter	Spring
Gadid	59.5	47.4	77.9	75.0
Trisopterus	8.6	5.9	8.1	9.0
Sandeel	0.9	1.2	0.3	0.9
Flatfish	2.6	5.0	0.9	4.8
Sandy benthic	12.8	10.6	6.2	1.7
Scorpion fish	0.0	1.1	2.0	1.0
Pelagic	13.4	25.5	4.6	7.6
Salmonid	0.0	0.0	0.0	0.0
Cephalopod	2.0	1.8	0.0	0.0
Other	0.2	1.4	0.0	0.0

Table 7

Variation in the number of scats collected with hard prey remains, observed and rarefied species richness and species evenness across each region and season. WC = west coast of Scotland.

Region	No. scats	Observed No. prey species	Species richness (S)	Variance	Species Evenness (PIE)
Summer					
The Wash	122	23	18	3	0.77
Moray Firth	89	25	18	3	0.16
Orkney	117	30	20	3	0.33
Shetland	47	21	17	2	0.37
Outer Hebrides	99	23	18	2	0.71
WC - north	93	26	21	4	0.75
WC - central	82	27	21	5	0.81
WC - south	83	36	27	13	0.81
Autumn					
The Wash	81	25	14	4	0.80
Moray Firth	21	16	14	7	0.06
Orkney	113	23	13	1	0.49
Shetland	111	27	14	1	0.48
WC - central	139	32	18	3	0.73
WC - south	134	43	21	5	0.81
Winter					
The Wash	62	24	18	2	0.61
Moray Firth	52	17	13	1	0.19
WC - central	71	37	26	10	0.82
WC - south	34	21	18	2	0.79
Spring					
The Wash	23	11	10	3	0.45
Moray Firth	103	19	9	1	0.05
Orkney	23	17	14	4	0.19
Shetland	28	14	12	2	0.69
WC - north	43	23	16	4	0.74
WC - central	80	31	20	3	0.87
WC - south	57	29	21	10	0.84

4.4 Sex-Specific Variation in Diet

The number of confirmed male and female seal scats by season and region is given in Table 8. The diet composition of male and female harbour seals is given in Table 9 and summarised by prey group (gadids, flatfish, etc.) in Table 10. 95% confidence intervals for prey species and groups are given in Appendices 4 and 5, respectively.

The Wash: Across all seasons, the diet of male harbour seals was dominated by scorpion fish, flatfish, sandy benthic prey, and gadids with important contributions of sandeel. The diet of female harbour seals was dominated by sandy benthic prey with important contributions of flatfish, scorpion fish, sandeel and pelagic species. The dominant prey species was bullrout in the male diet and dragonet in female diet. Gobies were important in female diet but made very little contribution to male diet. Seasonal variation in prey composition was observed in both male and female diets with fluctuations in whiting, sandeel, flatfish, dragonet and pelagic prey.

Moray Firth: Sandeel dominated the diet of both male and female harbour seals in the Moray Firth, making up >70% of the diet across all seasons. The only other major contributor to the diet was flatfish, mainly dab, flounder and plaice. Sandeel contributed least to the diet in summer and sprat peaked in the diet in autumn/winter. Salmonid prey peaked in the diet of females in autumn/winter (5.1%) and in male diet in summer (1.9%).

West Coast - central: The diet of female harbour seals could not be assessed seasonally in the West coast - central region due to small sample size. Across all seasons the diet of both male and female harbour seals in the West coast - central region was dominated by gadids and pelagic prey. Other important prey types for both sexes were sandy benthic species and *Trisopterus* species. The largest single contributor to the diet of male harbour seals was blue whiting with supporting contributions of dragonet and mackerel. Female diet was dominated by mackerel with important contributions of dragonet and cod.

West coast - south: The diet of female harbour seals could not be assessed seasonally in the West coast - south region due to small sample size. Across all seasons male diet was dominated by gadid prey, mainly haddock, whiting, cod and ling. Pelagic prey were also important. Gadids were also the main prey type consumed by female harbour seals in this region. *Trisopterus* species and pelagic prey also featured. Whiting was the dominant prey species consumed by females followed by poor cod and herring.

Differences in species richness of male and female diets were generally small across regions and seasons (Table 11). The largest differences were seen across all seasons in the West coast - central region and in the summer in The Wash where males consumed more prey species than females.

Across all seasons, differences in the evenness of the diet of male and female harbour seals were also generally small. In The Wash the diet of both sexes was fairly even (Table 11), in the Moray Firth diet was very uneven for both sexes and in the West coast central and south the diet was quite even and similar between the sexes. Seasonal comparisons showed that in The Wash, female diet was more uneven in winter and spring than male diet (Table 11).

Table 8: Summary of seasonal and regional variation in the number of confirmed male and female scats that contained otoliths. To improve sample size in some regions/seasons, scats were grouped across years/season.

Female

Region	Season	Year	No. scats	Otoliths	
				Total	Measured
The Wash	Summer	2011	51	1771	1054
The Wash	Summer	2012	16	714	431
The Wash	Autumn	2011	34	816	664
The Wash	Autumn	2012	14	270	240
The Wash	Winter	2012	19	940	430
The Wash	Winter	2013	2	25	24
The Wash	Spring	2011	29	787	412
The Wash	Spring	2012	18	1102	456
SE Scotland	Summer	2010	2	972	246
SE Scotland	Autumn	2010	1	21	21
SE Scotland	Spring	2011	1	125	34
Moray Firth	Summer	2010	40	5043	1734
Moray Firth	Autumn	2010	9	815	348
Moray Firth	Winter	2011	24	911	411
Moray Firth	Spring	2011	40	3797	1374
Shetland	Autumn	2011	1	2	2
WC - central	Summer	2010	10	124	123
WC - central	Autumn	2010	10	271	156
WC - central	Winter	2011	5	30	30
WC - central	Spring	2011	2	5	5
WC - south	Summer	2010	7	517	311
WC - south	Autumn	2010	13	544	362
WC - south	Winter	2010	7	170	144
WC - south	Spring	2010	4	187	112
WC - south	Spring	2011	4	79	78

Male

Region	Season	Year	No. scats	Otoliths	
				Total	Measured
The Wash	Summer	2011/2012	81	2389	1562
The Wash	Autumn	2011/2012	96	1951	1613
The Wash	Winter	2011/2012	43	760	387
The Wash	Spring	2011/2012	18	190	170
Moray Firth	Summer	2010	31	3260	1299
Moray Firth	Autumn/ Winter	2010	19	1288	511
Moray Firth	Spring	2011	36	2234	952
WC - central	Summer	2010	22	674	534
WC - central	Autumn	2010	102	2053	1357
WC - central	Winter	2011	35	1841	1001
WC - central	Spring	2011	42	484	431
WC - south	Summer	2010	34	1854	1493
WC - south	Autumn	2010	66	746	740
WC - south	Winter	2010	8	43	43
WC - south	Spring	2010/ 2011	59	576	573

Table 9

Comparison of male (M) and female (F) harbour seal diet (expressed as the percentage of each species in the diet by weight). Prey species listed are those contributing >2% for either sex in any season across each region (A) The Wash, (B) Moray Firth, (C) West coast - central and (D) West coast - south. 95% confidence intervals are given in Appendix 4.

A) The Wash

	Summer		Autumn		Winter		Spring		All seasons	
Species	**M**	**F**	**M**	**F**	**M**	**F**	**M**	**F**	**M**	**F**
Cod	0.4	0.0	0.4	0.0	5.2	0.0	1.4	0.0	1.9	
Whiting	5.4	0.9	28.8	18.1	25.2	7.6	1.7	6.2	15.1	7.9
Sandeel	33.1	25.2	6.4	11.9	5.3	4.8	2.6	3.6	11.5	11.2
Plaice	8.3	7.3	13.8	2.9	2.6	0.1	1.4	0.5	6.4	2.7
Lemon sole	2.7	0.7	4.6	5.8	8.1	8.8	0.6	2.8	4.1	4.2
Unid. flatfish	1.3	1.7	5.1	2.3	0.4	0.1	0.1	0.4	1.7	1.1
Dover sole	3.5	7.8	8.9	0.5	1.7	1.6	11.8	14.4	8.0	5.7
Flounder	0.2	7.8	0.6	1.9	0.0	0.0	0.0	0.0	0.2	2.3
Dab	3.6	5.8	5.9	5.2	0.9	0.0	0.0	0.6	2.6	2.8
Brill	2.5	0.1	1.2	1.6	0.0	0.0	0.0	0.0	0.9	0.4
Dragonet	34.7	33.0	20.6	13.0	10.4	13.2	7.8	32.1	21.1	24.3
Goby	0.2	8.2	0.2	2.3	1.8	11.6	0.0	21.0	0.6	10.8
Hooknose	0.0	0.0	0.0	6.7	0.0	0.3	0.1	0.6	0.1	1.9
Bullrout	0.5	0.0	1.7	13.3	27.5	8.8	68.2	6.7	20.6	6.3
Sea scorpion	0.6	0.0	0.5	6.8	0.0	15.0	3.2	1.3	1.1	6.1
Mackerel	0.0	0.0	0.0	2.7	0.0	0.0	0.0	0.0	0.0	0.6
Herring	0.3	0.0	0.2	0.0	0.6	14.6	0.8	7.4	0.5	5.6
Sprat	0.0	0.0	0.0	0.0	3.0	13.6	0.0	1.2	0.8	4.3
Eledone	0.0	0.0	0.0	3.6	0.0	0.0	0.0	0.0	0.0	0.9
Loligo	0.8	0.0	0.9	0.0	4.8	0.0	0.0	0.0	1.7	

B) Moray Firth

	Summer		Autumn/Winter		Spring		All seasons	
species	**M**	**F**	**M**	**F**	**M**	**F**	**M**	**F**
Saithe	0.4	0.2	3.0	1.4	1.8	0.8	3.2	1.3
Sandeel	45.6	60.3	83.9	69.6	93.5	83.1	74.1	69.2
Plaice	11.8	12.7	1.2	1.5	0.2	0.6	3.8	4.1
Unid. flatfish	5.6	3.2	1.4	1.0	1.2	2.0	2.6	1.9
Flounder	0.9	1.5	0.0	4.3	1.8	9.9	0.7	5.5
Dab	21.4	15.3	3.0	1.4	0.0	0.7	7.0	4.6
Bullrout	0.0	4.7	0.0	5.7	0.0	0.2	0.0	4.1
Sprat	0.0	0.0	4.4	5.2	0.3	1.3	2.8	3.2
Unid. Salmonid	1.9	0.0	0.0	5.1	0.0	0.0	0.5	2.5
Loligo	6.8	0.1	0.0	0.6	0.0	0.0	1.6	0.4

C) West coast - central

Species	Sum M	Aut M	Win M	Spr M	All seasons M	All seasons F
Cod	0.0	3.2	0.0	2.8	1.3	10.4
Whiting	14.6	1.7	10.7	0.5	6.5	4.8
Haddock	0.7	2.1	0.3	9.8	3.1	1.0
Saithe	0.0	2.5	5.0	8.1	5.7	1.1
Ling	2.3	1.9	5.6	4.4	3.5	4.2
Unid. gadid	4.9	0.5	2.5	1.0	2.1	1.1
Saithe or Pollock	0.0	0.4	4.8	0.0	1.7	0.0
Blue whiting	35.7	0.6	16.6	23.3	17.9	4.2
Poor cod	3.0	3.7	14.7	2.8	5.8	5.0
Norway pout	2.5	1.3	5.2	2.2	2.7	2.1
Sandeel	2.7	8.4	2.6	3.5	4.3	3.9
Plaice	0.0	2.5	0.0	0.0	0.6	0.0
Lemon sole	0.4	0.2	0.0	2.9	0.9	0.0
Dragonet	0.0	24.2	20.9	0.8	11.5	12.0
Unid. Cottidae	20.1	1.9	0.0	0.0	5.5	1.8
Gurnard	0.0	0.0	0.5	0.0	0.1	2.1
Mackerel	7.4	21.8	0.0	27.0	14.4	36.2
Herring	1.7	11.5	3.3	2.3	4.7	6.4
Horse mackerel	0.0	5.7	1.0	0.1	1.6	1.2
Eledone	2.3	0.7	0.0	3.0	1.4	0.0
Loligo	0.0	0.4	0.0	2.7	0.7	1.9

D) West coast - south

Species	Sum M	Aut M	Win M	Spr M	All seasons M	All seasons F
Cod	7.8	8.4	0.0	27.1	10.6	1.8
Whiting	22.0	9.5	9.3	10.8	13.2	24.0
Haddock	15.6	30.3	15.9	23.8	21.8	6.1
Saithe	0.3	1.0	0.0	0.0	0.5	2.1
Ling	1.6	2.5	38.8	5.2	9.8	0.0
Rockling	0.3	4.1	0.0	0.3	1.1	0.7
Unid. gadid	7.2	0.7	2.5	3.3	3.6	7.7
Blue whiting	6.0	0.0	0.5	5.5	3.1	2.1
Poor cod	3.0	1.2	4.6	1.4	2.9	12.5
Norway pout	3.7	0.0	0.8	2.7	1.8	5.5
Sandeel	0.5	1.8	0.4	2.2	1.2	0.9
Lemon sole	0.2	1.4	4.8	0.2	1.4	0.0
Witch	0.9	0.4	0.0	2.8	1.1	1.7
Dragonet	16.0	6.3	0.0	4.3	7.2	6.8
Bullrout	0.0	0.0	0.0	0.0	0.0	3.3
Gurnard	0.0	0.2	10.9	0.0	2.3	1.4
Mackerel	8.3	6.2	11.3	1.7	7.8	2.4
Herring	0.8	20.2	0.0	4.0	6.2	10.0
Argentine	0.3	0.2	0.0	2.0	0.7	0.4
Eledone	3.3	0.2	0.0	0.0	1.0	3.4
Eelpout	0.0	0.0	0.0	0.0	0.0	2.1

Table 10: Male (M) and female (F) harbour seal diet (expressed as the percentage of each prey group in the diet by weight) for each region and season. 95% confidence intervals are given in Appendix 5.

A) The Wash

	Summer		Autumn		Winter		Spring		All Seasons	
Prey type	**M**	**F**	**M**	**F**	**M**	**F**	**M**	**F**	**M**	**F**
Gadid	5.9	0.9	29.2	18.1	30.4	7.6	3.1	6.2	17.0	7.9
Trisopterus	0.4	0.0	0.0	0.4	1.8	0.0	0.1	0.2	0.6	0.1
Sandeel	33.1	25.2	6.4	11.9	5.3	4.8	2.6	3.6	11.5	11.2
Flatfish	22.2	31.3	40.2	20.3	13.7	10.6	14.0	18.9	23.9	19.3
Sandy benthic	35.0	41.6	20.7	16.0	12.2	24.7	7.8	53.1	21.7	35.2
Scorpion fish	1.3	0.2	2.2	26.8	27.5	24.0	71.5	9.5	21.8	14.6
Pelagic	0.3	0.2	0.2	2.8	4.3	28.2	0.8	8.5	1.5	10.5
Salmonid	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cephalopod	0.8	0.1	0.9	3.6	4.8	0.0	0.0	0.0	1.7	0.9
Other	1.0	0.5	0.2	0.1	0.0	0.0	0.0	0.0	0.3	0.2

B) Moray Firth

	Summer		Autumn/Winter		Spring		All Seasons	
Prey type	**M**	**F**	**M**	**F**	**M**	**F**	**M**	**F**
Gadid	3.6	1.9	5.8	4.1	2.7	1.1	5.8	3.3
Trisopterus	0.0	0.0	0.1	0.3	0.0	0.0	0.1	0.2
Sandeel	45.6	60.3	83.9	69.6	93.5	83.1	74.1	69.2
Flatfish	40.9	33.0	5.6	8.2	3.5	14.1	14.6	16.4
Sandy benthic	0.6	0.0	0.1	0.3	0.0	0.0	0.2	0.2
Scorpion fish	0.0	4.7	0.0	5.7	0.0	0.2		4.1
Pelagic	0.7	0.0	4.4	5.2	0.3	1.3	3.0	3.3
Salmonid	1.9	0.0	0.0	5.1	0.0	0.0	0.5	2.5
Cephalopod	6.8	0.1	0.0	0.6	0.0	0.0	1.6	0.4
Other	0.0	0.1	0.0	0.9	0.0	0.2	0.0	0.5

C) West coast - central

	Summer	Autumn	Winter	Spring	All Seasons	
Prey type	**M**	**M**	**M**	**M**	**M**	**F**
Gadid	59.2	13.4	46.4	50.6	42.6	26.9
Trisopterus	5.6	5.5	20.3	5.1	8.8	7.6
Sandeel	2.7	8.4	2.6	3.5	4.3	3.9
Flatfish	0.6	6.3	3.0	4.9	3.7	0.1
Sandy benthic	0.1	24.2	20.9	0.8	11.5	12.0
Scorpion fish	20.3	1.9	2.4	0.0	6.1	3.9
Pelagic	9.1	39.1	4.4	29.4	20.8	43.9
Salmonid	0.0	0.0	0.0	0.0	0.0	0.0
Cephalopod	2.3	1.1	0.0	5.7	2.2	1.9
Other	0.1	0.0	0.0	0.0	0.0	0.0

D) West coast - south

Prey type	Summer M	Autumn M	Winter M	Spring M	All Seasons M	All Seasons F
Gadid	60.7	57.8	67.0	77.2	64.3	44.6
Trisopterus	6.8	1.3	5.7	4.2	5.0	18.5
Sandeel	0.5	1.8	0.4	2.2	1.2	0.9
Flatfish	2.4	4.4	4.8	4.3	3.8	4.7
Sandy benthic	16.0	6.3	0.0	4.3	7.2	7.4
Scorpion fish	0.0	0.2	10.9	0.0	2.3	4.7
Pelagic	9.9	26.6	11.3	7.9	14.9	12.8
Salmonid	0.0	0.0	0.0	0.0	0.0	0.0
Cephalopod	3.3	0.9	0.0	0.0	1.1	4.1
Other	0.4	0.7	0.0	0.0	0.2	2.3

Table 11: Variation in the number of scats collected that contained hard prey remains, observed number of prey species, rarefied species richness (S) and species evenness (PIE) for male and female diet within individual seasons and regions. Values should not be compared across seasons within a region or across regions because rarefaction was conducted on male and female samples within seasons.

A) The Wash

	No. scats	Observed No. prey species	Species richness (S)	Species evenness (PIE)
Summer				
Male	82	28	23	0.68
Female	67	21	19	0.77
Autumn				
Male	96	22	17	0.80
Female	48	27	22	0.83
Winter				
Male	43	20	14	0.70
Female	19	16	14	0.45
Spring				
Male	18	16	13	0.72
Female	47	19	14	0.41
All seasons				
Male	239	31	28	0.80
Female	181	35	31	0.72

B) Moray Firth

	No. scats	Observed No. prey species	Species richness (S)	Species evenness (PIE)
Summer				
Male	31	19	16	0.20
Female	40	15	13	0.18
Autumn / Winter				
Male	19	12	10	0.06
Female	33	17	13	0.16
Spring				
Male	36	10	8	0.01
Female	40	15	12	0.05
All seasons				
Male	86	25	21	0.11
Female	113	22	19	0.13

C) West coast - central

	No. scats	Observed No. prey species	Species richness (S)	Species evenness (PIE)
All seasons				
Male	166	38	23	0.82
Female	27	21	18	0.81

D) West coast - south

	No. scats	Observed No. prey species	Species richness (S)	Species evenness (PIE)
All seasons				
Male	166	38	23	0.82
Female	27	21	18	0.81

4.5 Prey Consumption

Estimated annual prey consumption by harbour seals in 2010/11 is given in Table 12 for the main species in the diet. Estimates of precision (95% confidence limits) are given in Appendix 6. 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), most prey consumed were taken from the southern North Sea and from Orkney and Shetland. West of Scotland (ICES Division VIa), the large majority of prey consumed were taken from the southern and central regions of the West Coast.

The same considerations regarding the width of estimated confidence intervals (Appendix 5) apply as for estimates of diet composition. Precision is greater for regions with larger sample sizes, for major components of the diet, and for combinations of regions.

Overall, harbour seals were estimated to have consumed 23,710 t (95% confidence interval: 21,900-26,170 t) of prey in the North Sea (ICES Subarea IV) and 29,950 t (95% confidence interval: 26,820-32,980 t) of prey west of Scotland (ICES Division VIa) in the 12 months from April 2010 to March 2011, and a grand total of 53,660 t (95% confidence interval: 50,180-57,400 t).

5 Discussion

5.1 Representativeness of Scat Samples

The study achieved its objectives of estimating harbour seal diet composition, size of prey consumed and prey consumption in 2010/11 in almost all regions/seasons around Scotland (and eastern England).

To minimise errors associated caused by including grey seal scats in samples, only scats from haul-out sites judged from counts to comprise >80% harbour seals were included in analysis. Molecular analysis of scats to determine species found that 97% of scats from these haul-out sites were from harbour seals (Wilson 2014). Any bias introduced as a result of including grey seal scats should therefore be small.

The sex ratio in scats in the samples is a function of the sex ratio of the seals hauled out, any difference in defaecation rate, and the sampling protocol. Determining the sex of harbour seals at haul-out sites is difficult (Thompson *et al.* 1998) and it was not possible to assess sex ratio at any of the haul-out sites visited. There is no information about variation in defaecation rate between sexes. The sampling protocol was to visit all major haul-out sites within each region and season regardless of the sex ratio of seals. For example, haul-out sites which both did and did not contain pups were visited in summer. This protocol should have ensured that scats were sampled in proportion to the sex ratio of the population hauled out.

Scats typically represent recent feeding (2-3 days, Wilson *et al.* 2013, Wilson 2014). Telemetry studies have shown that harbour seals around Britain are mostly distributed close to the coast (Cunningham *et al.* 2009, Sharples *et al.* 2012; Jones *et al.* 2013). Bias due to differental sampling of diet in inshore and offshore waters is therefore not expected.

Table 12: Estimated harbour seal annual prey consumption (in tonnes) in 2010/11. WC = west coast. 95% confidence intervals are given in Appendix 6.

	North Sea						West of Scotland				
Prey species	**Southern North Sea**	**Southeast Scotland**	**Moray Firth**	**Orkney**	**Shetland**	**TOTAL**	**Outer Hebrides**	**WC - north**	**WC - central**	**WC - south**	**TOTAL**
Cod	146	26	19	1,091	43	1,325	139	149	417	2,152	2,857
Whiting	1,299	57	13	40	21	1,430	85	90	649	2,506	3,331
Haddock	0	3	7	105	14	129	48	26	340	3,069	3,482
Saithe	0	10	47	605	957	1,619	62	135	346	786	1,330
Ling	0	0	0	117	249	366	100	201	323	396	1,020
Poor cod	3	0	3	46	168	221	161	118	651	839	1,770
Norway pout	0	0	0	2	245	247	759	211	463	321	1,753
Sandeel	832	127	1,645	2,416	1,400	6,420	500	96	477	125	1,198
Plaice	497	194	86	63	35	875	68	12	61	127	268
Lemon sole	324	3	2	9	67	405	0	1	72	80	153
Unid. flatfish	194	26	42	26	8	296	8	0	39	42	89
Dover sole	1,129	0	0	0	0	1,129	0	0	9	11	20
Megrim	0	0	3	0	0	3	0	0	8	0	8
Mackerel	0	25	6	250	319	600	482	140	1,312	853	2,788
Herring	119	1	9	587	1,328	2,045	185	134	381	969	1,670
Sprat	199	32	65	0	4	299	0	0	0	0	0
Bullrout	565	5	59	15	0	644	0	0	9	36	44
Sea Scorpion	129	0	0	39	0	168	0	0	5	0	5
Dragonet	2,098	9	10	95	584	2,796	106	8	838	1,160	2,112
Other	1,254	173	277	341	652	2,697	1,123	251	2,742	1,933	6,050
Total	**8,789**	**691**	**2,293**	**5,847**	**6,094**	**23,714**	**3,829**	**1,570**	**9,143**	**15,407**	**29,948**

5.2 Diet Composition

In the North Sea and Northern Isles, sandeel was an important prey throughout the year. Regional and seasonal importance of prey species was observed particularly in flatfish in the northern and southern North Sea and pelagic, gadid and benthic species in the Northern Isles. On the Scottish west coast, large gadids dominated the diet with seasonal pulses of pelagic prey. Wilson (2014) reviewed information on fish prey species and found that variation in diet appeared to correspond largely to regional and seasonal differences in prey distribution and abundance.

Comparison of results with previous studies is affected by differences in the use of digestion correction factors; in particular, except for Sharples *et al.* (2009), previous studies of harbour seal diet around Scotland and England have not used recovery rates (number correction factors) to account for species-specific variation in complete digestion of otoliths. Consequently, of the main prey species, the contribution to the diet of sandeel and herring, which have relatively low rates of recovery, will have been underestimated in earlier studies.

Discussion of the prevalence of sandeel in the diet compared with previous studies is included below in the section: The relationship between harbour seal diet and population trend.

5.3 Size of Prey Consumed

The large majority (95%) of fish consumed by harbour seals were <30 cm in estimated length and the mean length of each species was below the minimum landing size for commercial catches of cod (35 cm), haddock (30 cm), whiting (27 cm) and plaice (27 cm) in almost all regions/seasons. Whether or not predation on smaller, and, therefore, younger, fish has a greater impact on fish stocks than predation on larger/older fish depends on the level of size/age-specific seal predation relative to other components of mortality and to the size/age structure of the fish stock. This can only be assessed robustly by incorporating seal predation in fish stock assessments. However, because mortality rates of the main fish species in the diet of harbour seals are mostly high, predation on the much larger younger age classes of fish is likely to have less of an effect than would predation on the much smaller older age classes. If so, this suggests that the interaction between harbour seals and commercial fisheries around Scotland may not be important for most fish species.

5.4 The Relationship between Harbour Seal Diet and Population Trend

Overall, no clear consistent pattern emerged to link estimated diet composition of harbour seals (Tables 5, 6) with observed population trends (Lonergan *et al.* 2007, Duck *et al.* 2014). Instead, as noted above, variation in diet generally appeared to correspond largely to regional and seasonal differences in prey distribution and abundance (Wilson 2014). However, a relationship can be seen between measures of diet diversity and population trend. Table 7 shows that prey species richness and evenness were generally lower in

Shetland, Orkney and the Moray Firth, where harbour seals have declined, and higher in the west coast of Scotland and The Wash, southern North Sea, where harbour seals have not declined.

5.4.1 The Importance of Sandeel in the Diet

Diet composition results (Tables 5, 6) show that sandeel was an important component in harbour seal diet in Shetland, Orkney and the Moray Firth and quite important in southeast Scotland - all regions where populations have shown declines since around 2000 ((Lonergan *et al.* 2007; Duck *et al.* 2014). Sandeel was not an important component of the diet west of Scotland, where populations have remained stable, nor in the southern North Sea, where the population is increasing (Duck *et al.* 2014).

As noted above, most previous studies of harbour seal diet did take account of complete digestion of otoliths using recovery rates (number correction factors), which means that the contribution to the diet of sandeel and herring will have been underestimated. Nevertheless, it is possible to take this into account qualitatively and, therefore, assess generally whether the contribution of sandeel to harbour seal diet has changed over time.

In Shetland, previous studies found sandeel to contribute mostly 15-30% but as high as 50-60% to the diet in 1994-97 (Brown and Pierce 1997, 1998, Brown *et al.* 2001). In 2010/11, sandeel made up 7-36% of the diet (Table 6). Given the underestimation of sandeel in the earlier studies, it is likely that sandeel have declined in importance in the diet of harbour seals in Shetland. In southeast Scotland, sandeel in the diet declined markedly from 71-77% in 1998-2003 (Sharples *et al.* 2009) to 18% in 2010/11 (Table 6). There is no information on harbour seal diet in Orkney prior to 2010/11.

In the Moray Firth, previous studies found a variable amount of sandeel in the diet of harbour seals, which ranged from 8% to 82% (Thompson *et al.* 1996; Tollit and Thompson 1996; Tollit *et al.* 1997). In 2010/11, sandeel made up 58-85% of the diet (Table 6). Thus, it is possible to conclude that sandeel remains an important part of the diet in this region.

In The Wash, southern North Sea, Hall *et al.* (1998) found that sandeel contributed only 3% to the diet of harbour seals in 1990-1992. In 2010/11, sandeel contributed a similarly small amount (3-7%), except in summer (22%; Table 6). West of Scotland, Pierce and Santos (2003) found sandeel to be a very small part of the diet of harbour seals (1-4%) in the central region in 1993-94. In 2010/11, sandeel remained a similarly small component of the diet in this region (4-7%; Table 6).

Sandeel biomass has declined in the northern North Sea and Northern Isles since 2000 (ICES Advice 2015) and seabird breeding failure in the northwest North Sea has been linked to a reduction in the availability of sandeel (Wanless *et al.* 2004) and to reduced sandeel recruitment in warm winters (Frederiksen *et al.* 2004). In contrast, sandeel biomass has

increased in the southern North Sea since 2000 (ICES Advice 2015). There is no stock assessment of sandeel west of Scotland.

Although there are gaps in the relevant information, a general pattern that emerges from these comparisons is that in regions where harbour seals have declined (northern and eastern Scotland) sandeel stocks have also declined and, although their contribution to the diet has declined, they remain an important component of the diet. In regions where harbour seals have not declined (west coast of Scotland, southern North Sea), sandeel were and remain unimportant in the diet and, in the southern North Sea, sandeel stocks have increased.

Overall, with the caution that information is incomplete, the diet of harbour seals is less diverse and at least partially reliant on declining sandeel stocks in regions where population declines have been observed, and is more diverse and not reliant on sandeels in regions where population declines have not been observed. A tentative conclusion is that declines in harbour seal abundance in northern regions may be linked to a decline in the abundance of sandeels.

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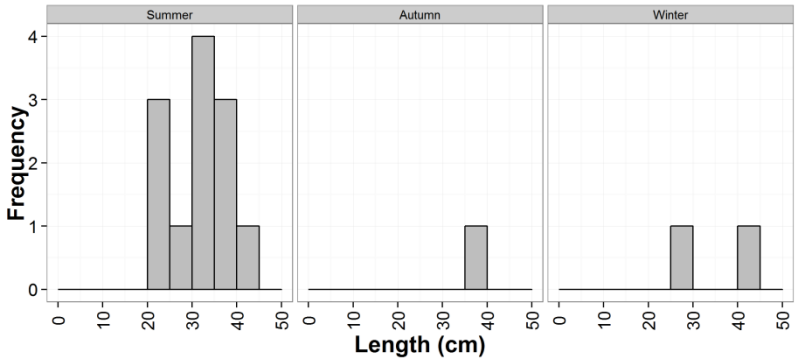
8 Appendices

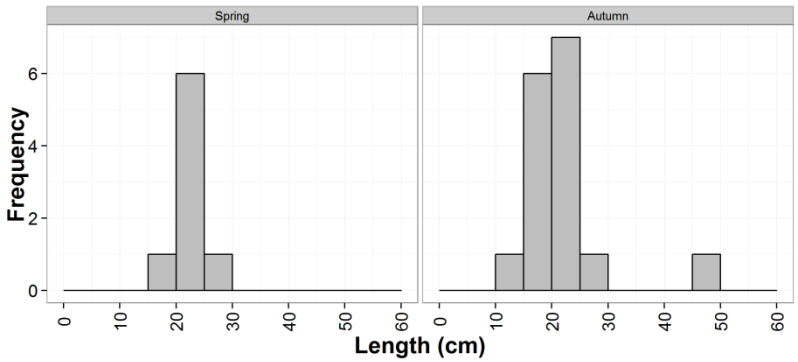
8.1 Appendix 1: Length-frequency histograms for the nine major prey species in harbour seal diet in each region and season where prey remains were available.

Cod (minimum landing size: 35cm)

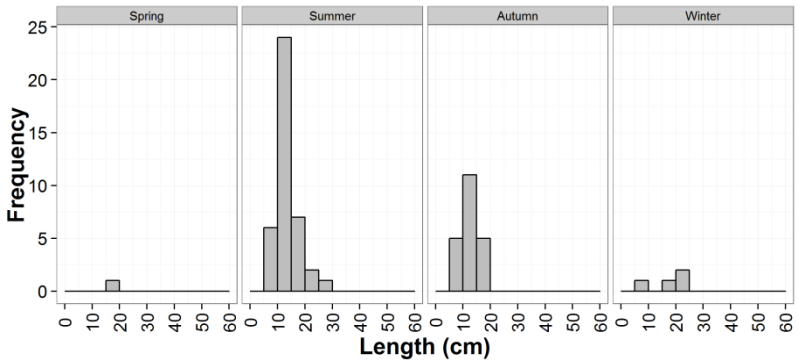
A) England



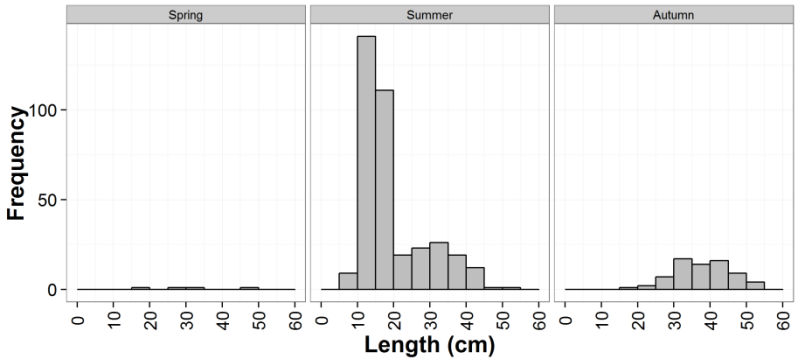
B) southeast Scotland



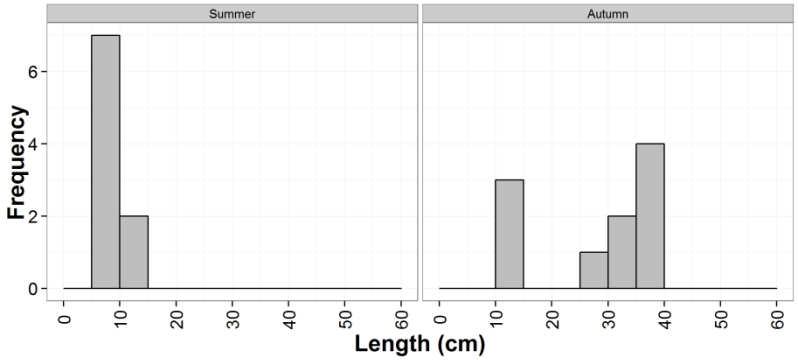
C) Moray Firth



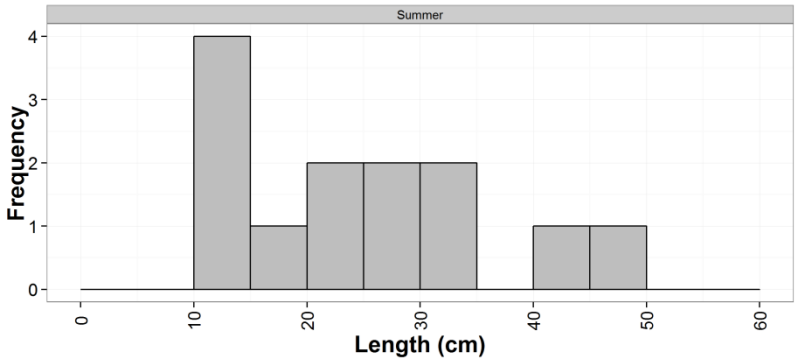
D) Orkney



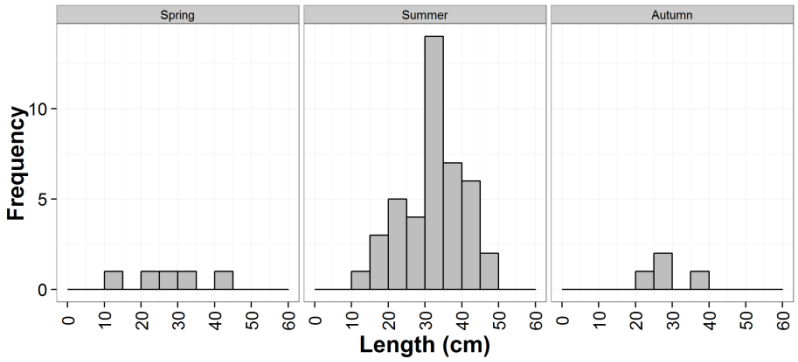
E) Shetland



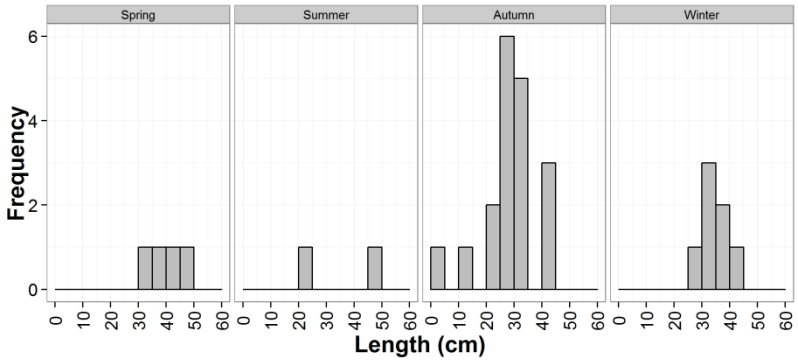
F) Outer Hebrides



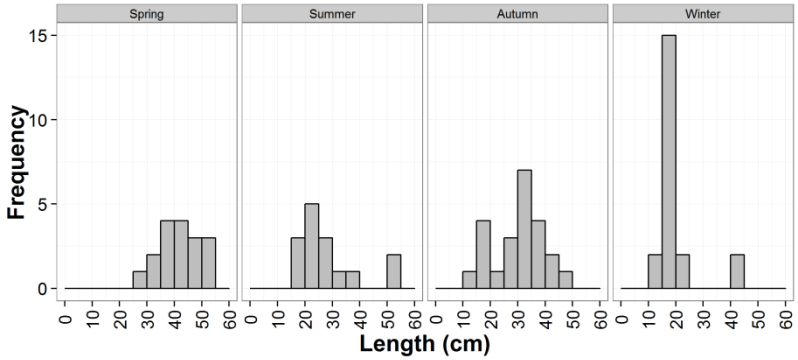
G) West coast – north



H) West coast – central

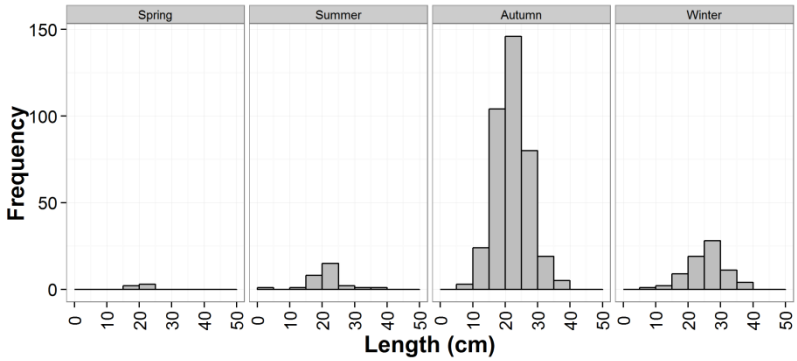


I) West coast – south

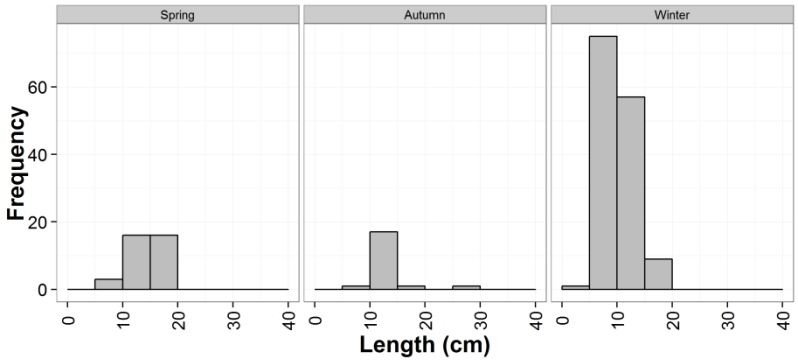


Whiting (minimum landing size: 27cm)

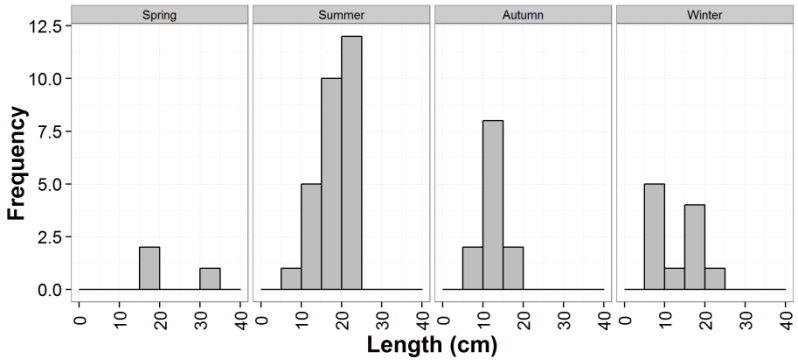
A) England



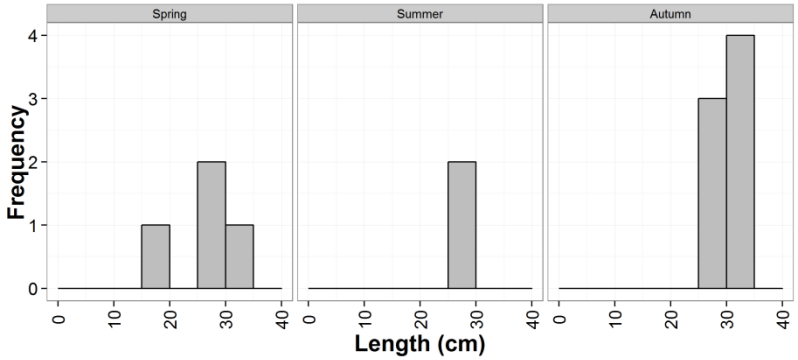
B) southeast Scotland



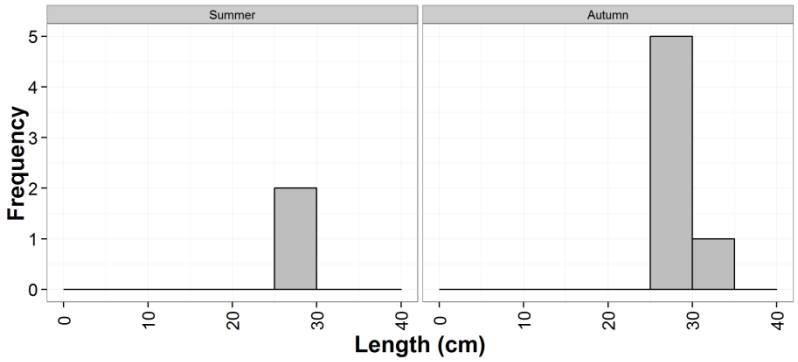
C) Moray Firth



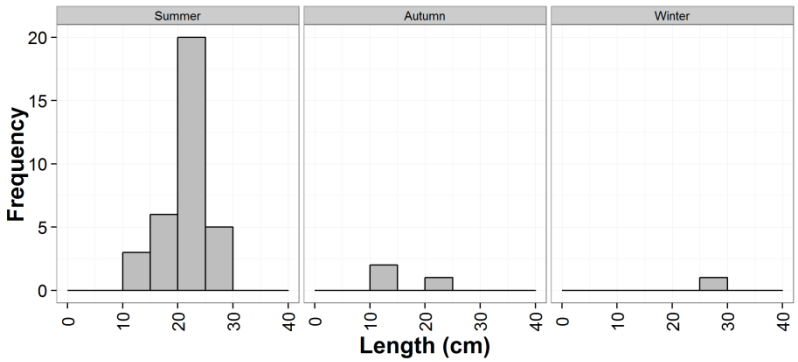
D) Orkney



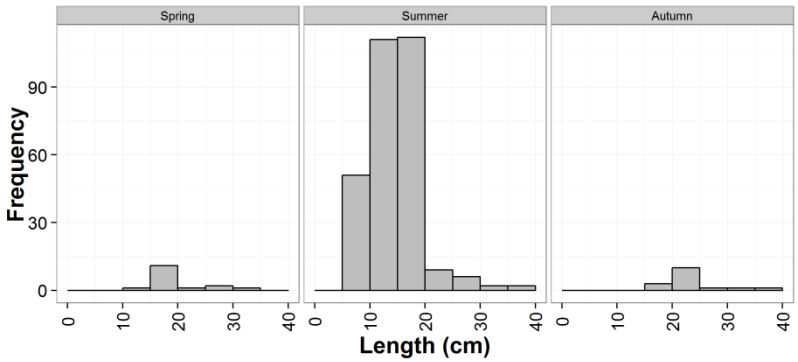
E) Shetland



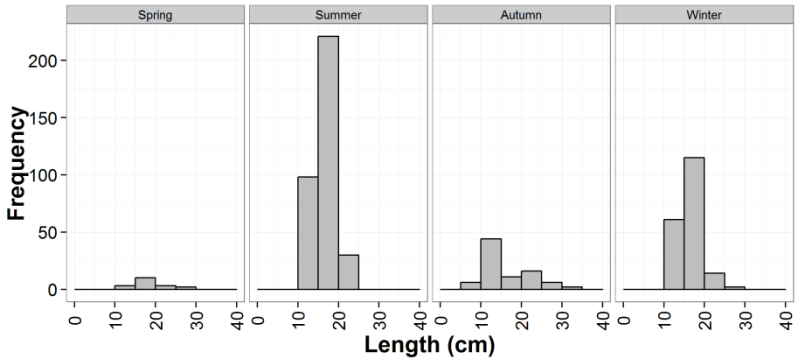
F) Outer Hebrides



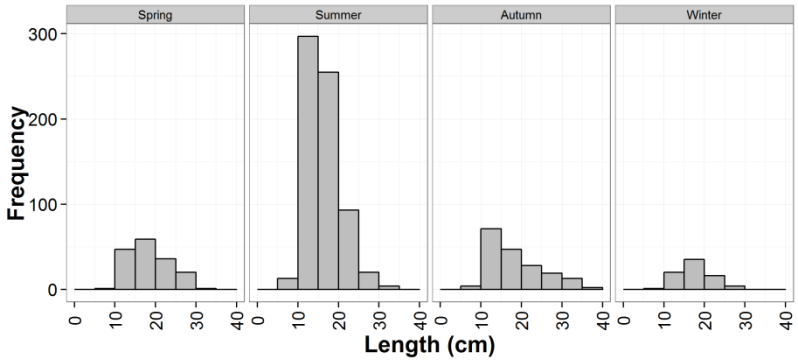
G) West coast – north



H) West coast – central

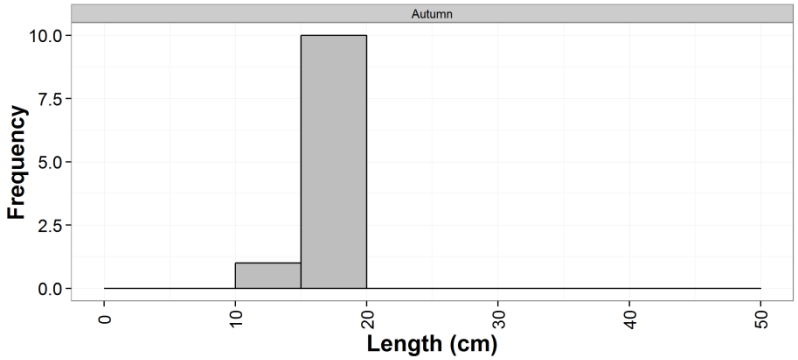


I) West coast – south

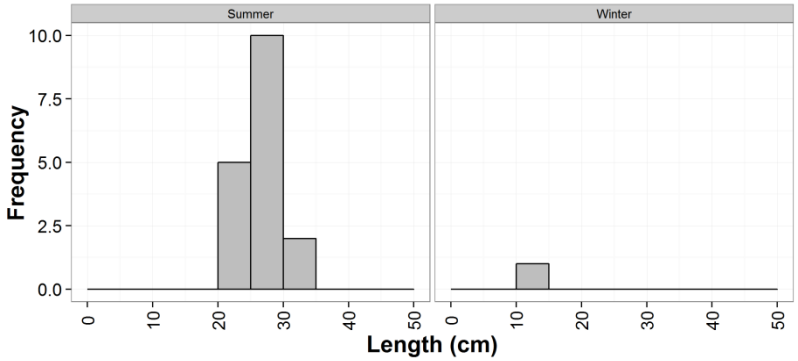


Haddock (minimum landing size: 30cm)

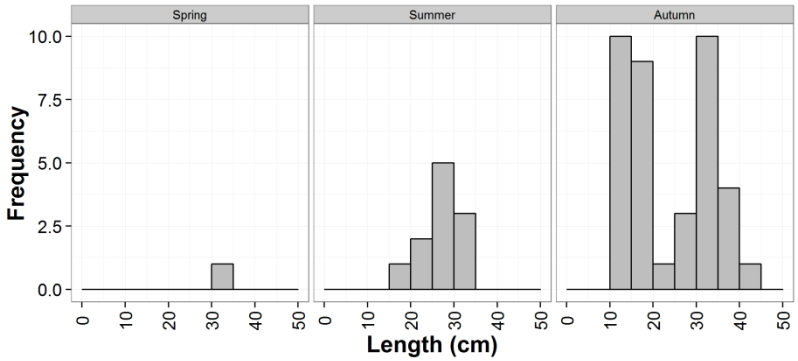
A) southeast Scotland



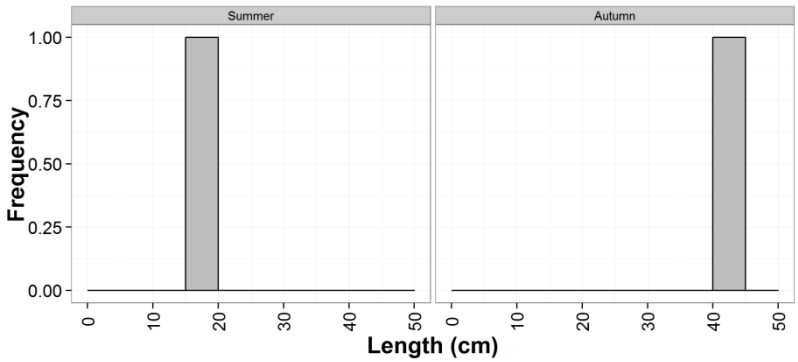
B) Moray Firth



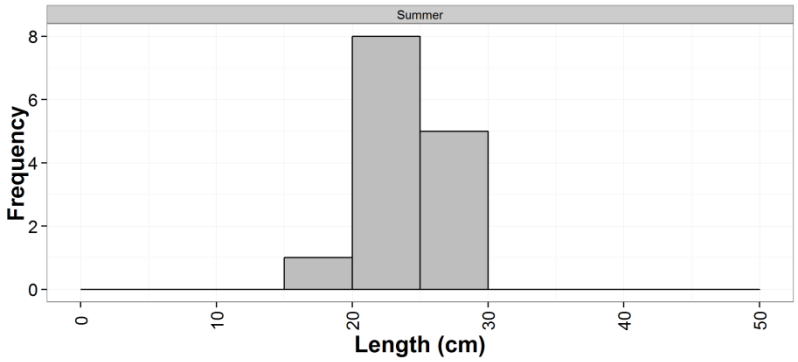
C) Orkney



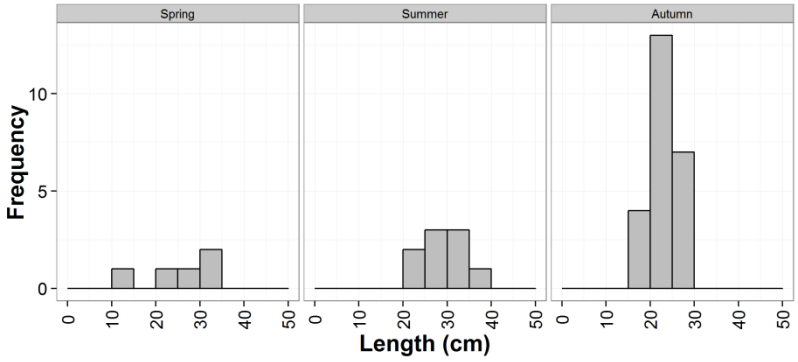
D) Shetland



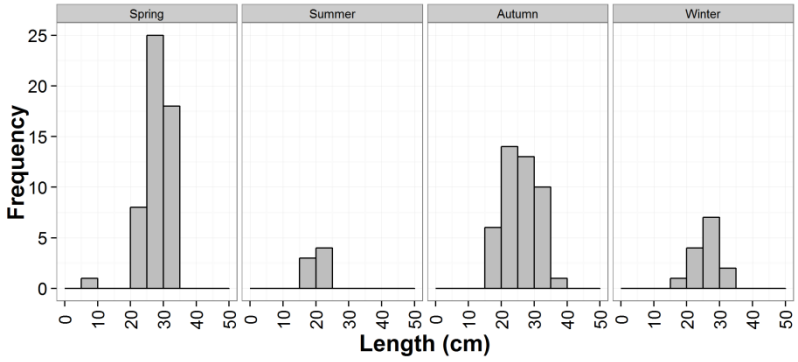
E) Outer Hebrides



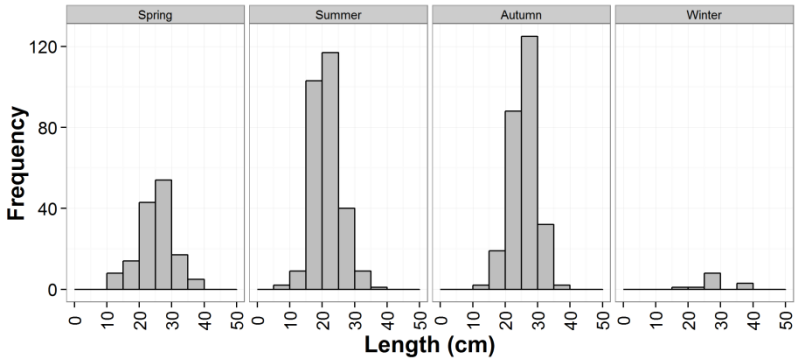
F) West coast – north



G) West coast – central

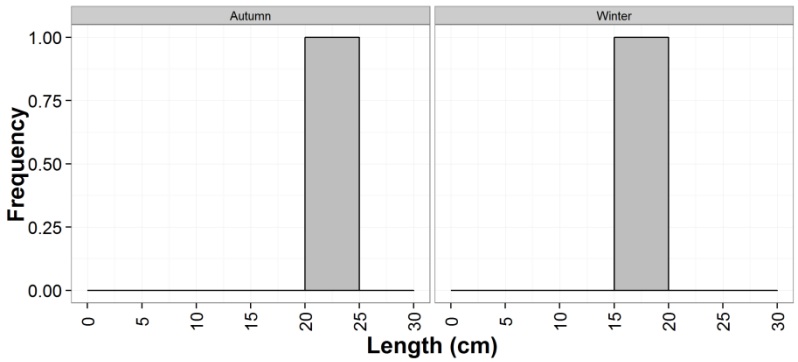


H) West coast – south

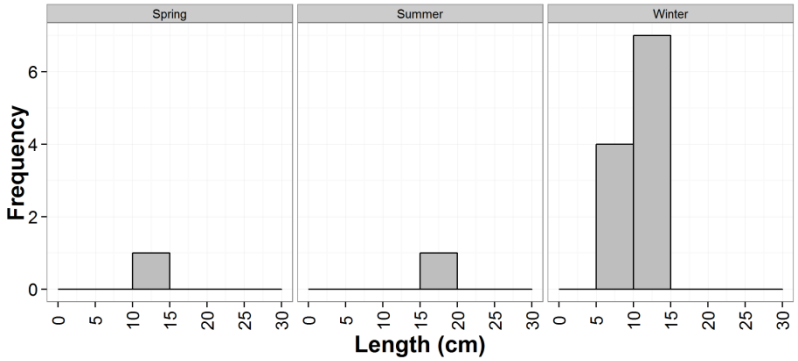


Poor cod

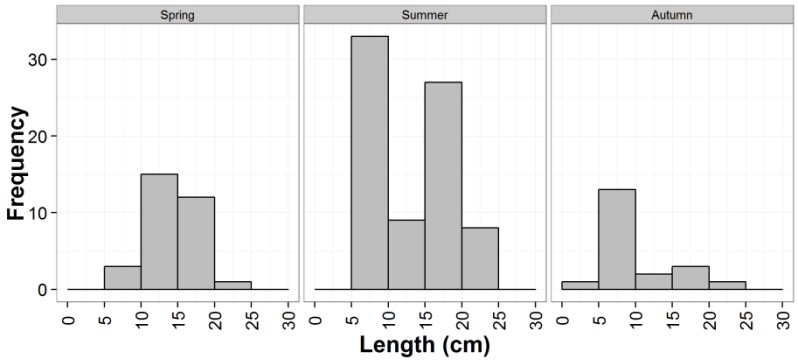
A) England



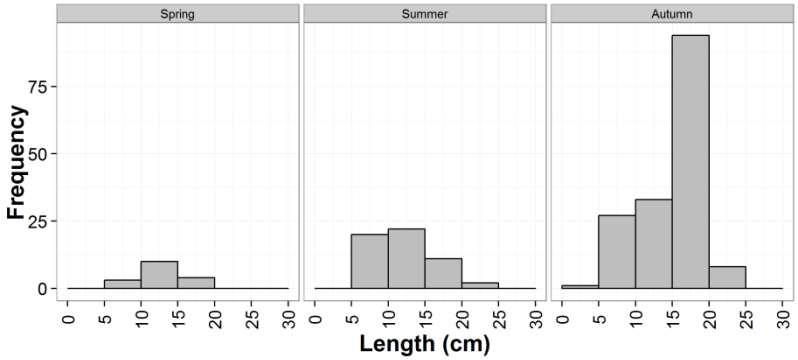
B) Moray Firth



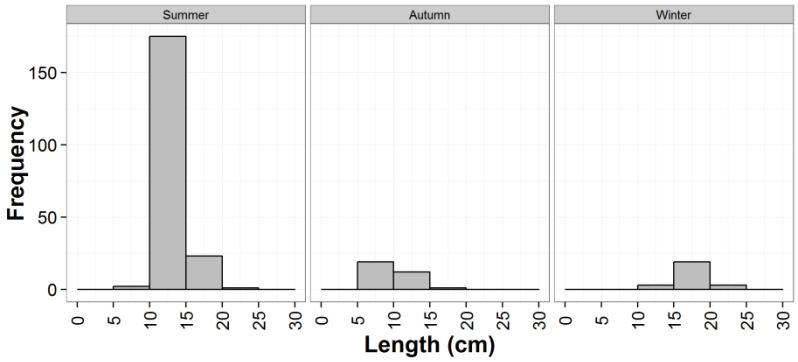
C) Orkney



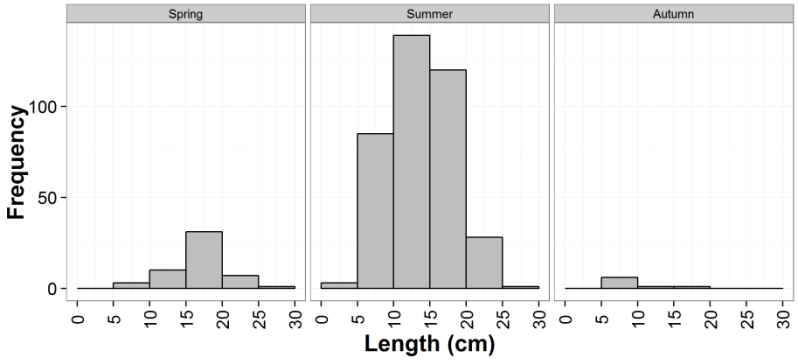
D) Shetland



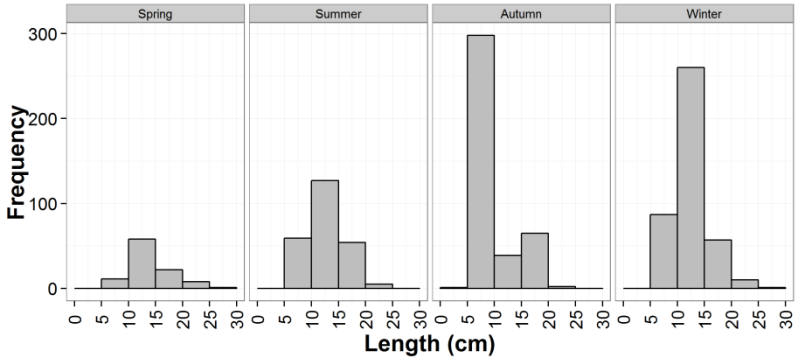
E) Outer Hebrides



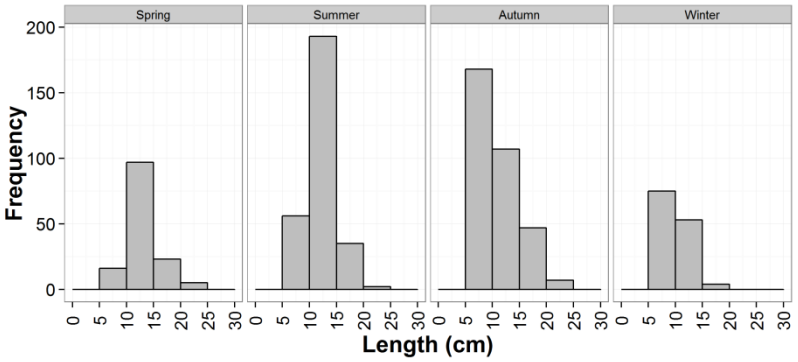
F) West coast – north



G) West coast – central

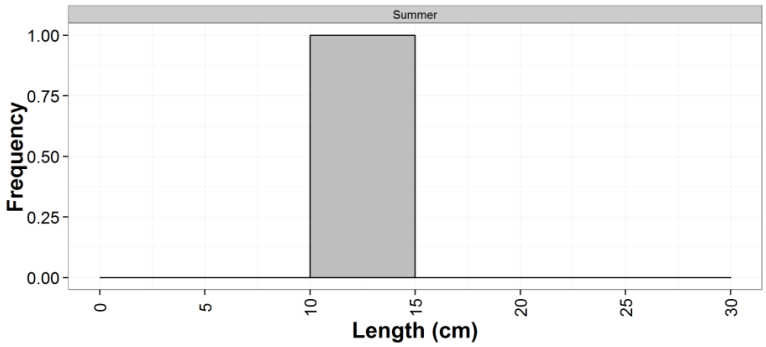


H) West coast – south

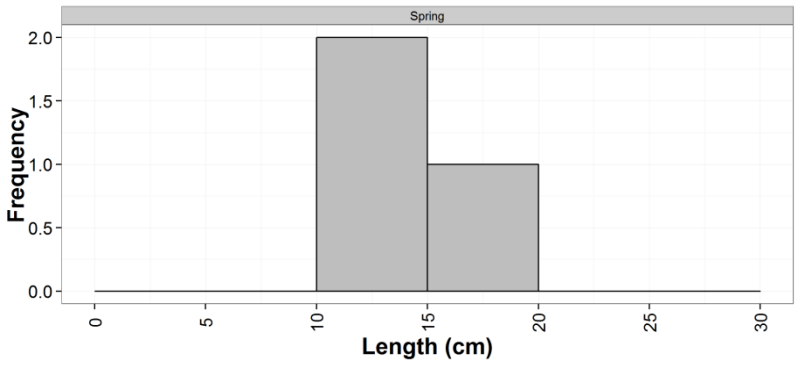


Norway pout

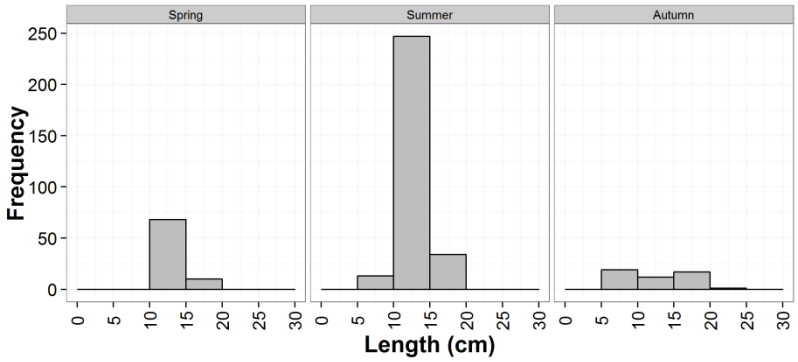
A) Moray Firth



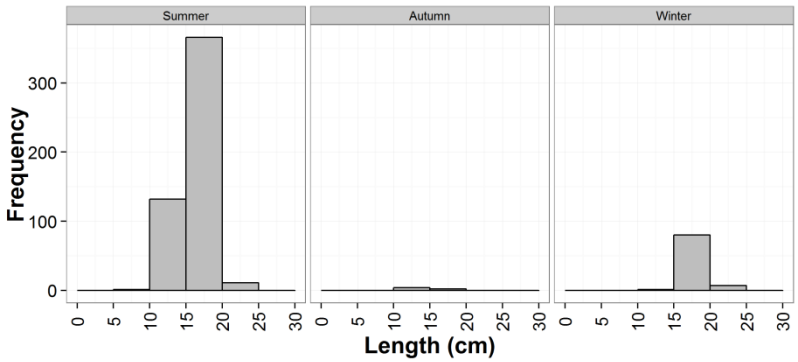
B) Orkney



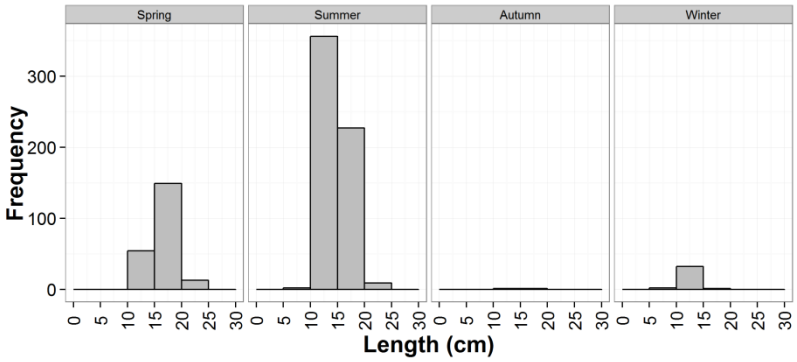
C) Shetland



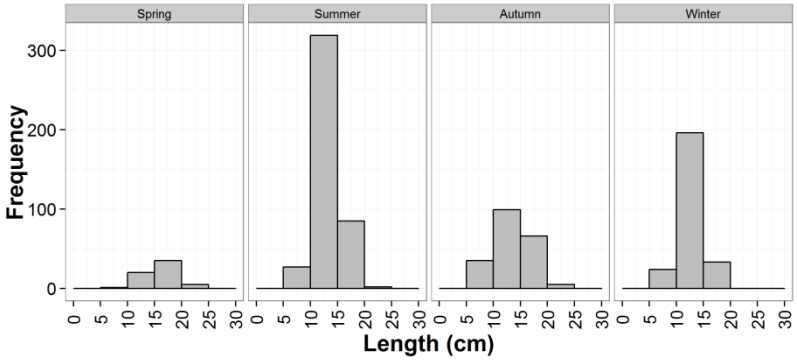
D) Outer Hebrides



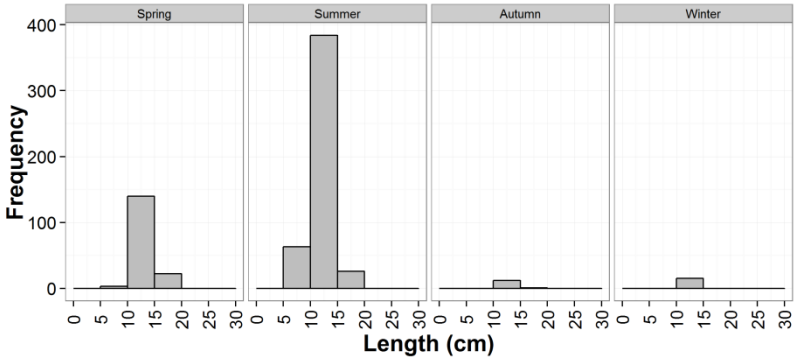
E) West coast – north



F) West coast – central

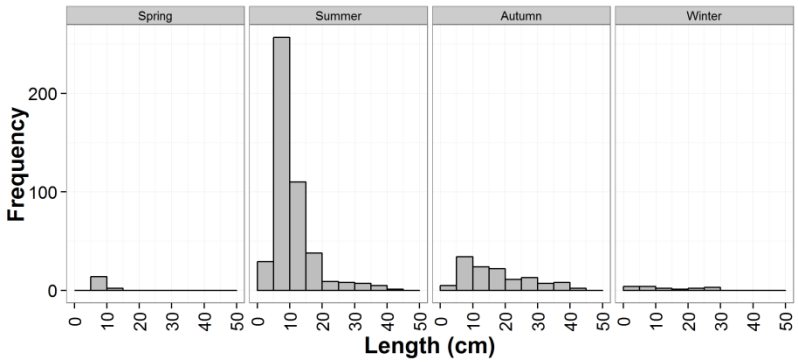


G) West coast – south

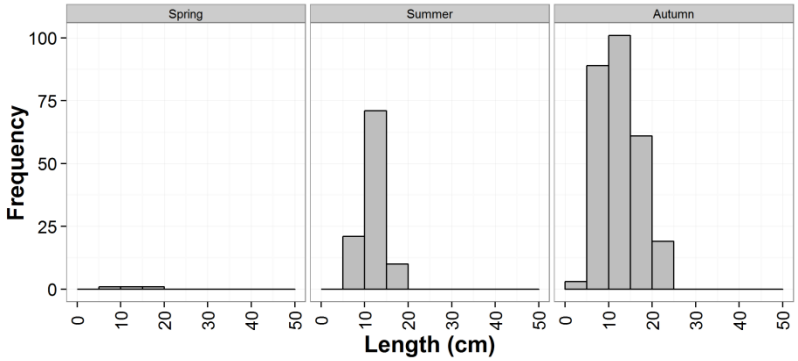


Plaice (minimum landing size: 27cm)

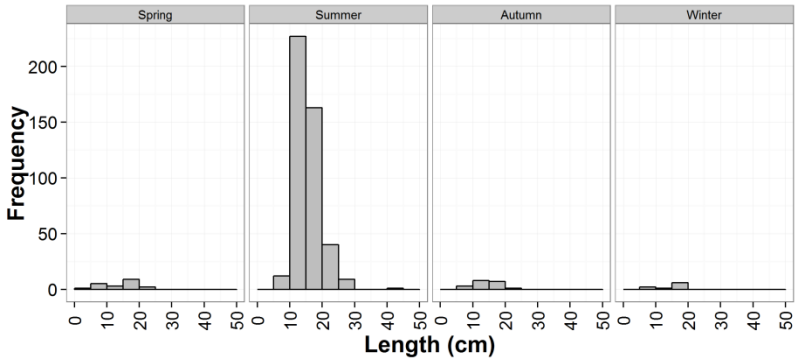
A) England



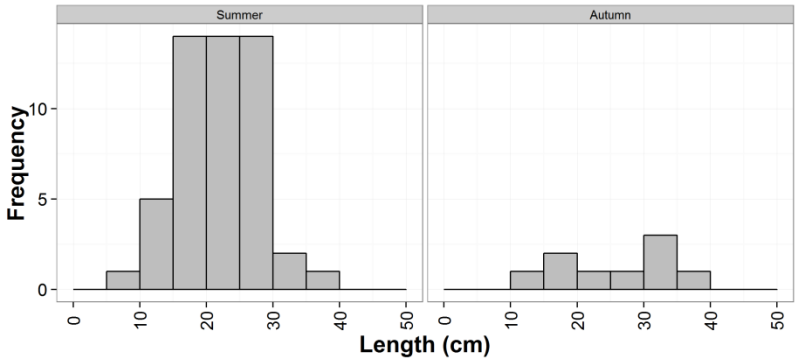
B) southeast Scotland



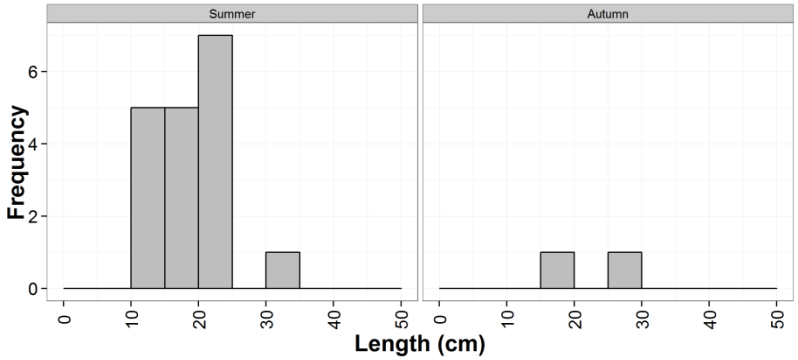
C) Moray Firth



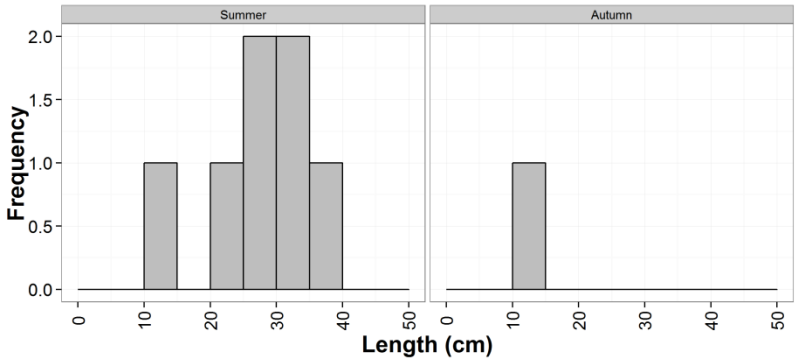
D) Orkney



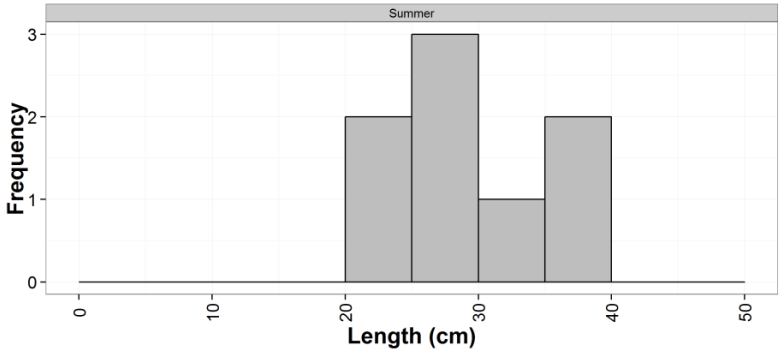
E) Shetland



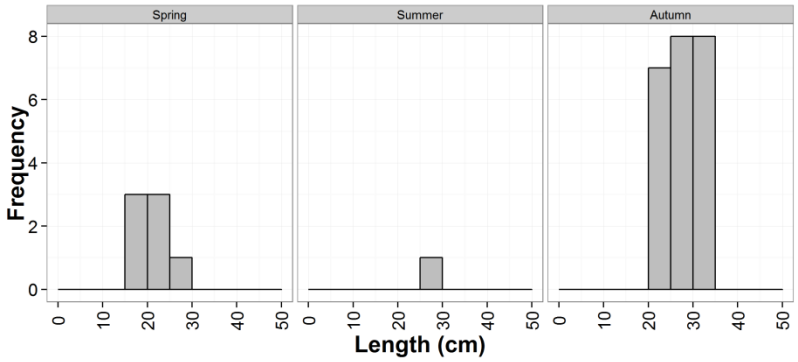
F) Outer Hebrides



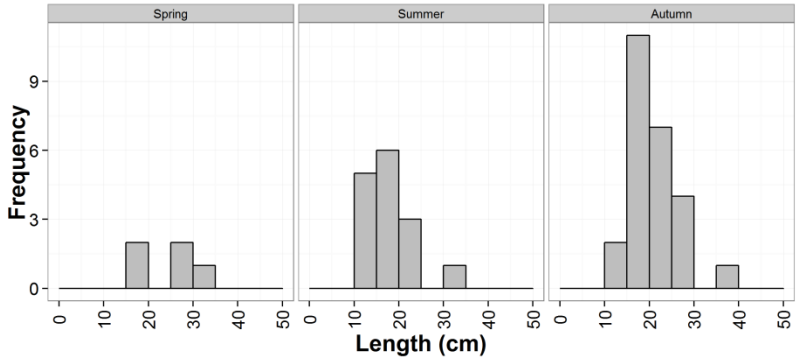
G) West coast – north



H) West coast – central

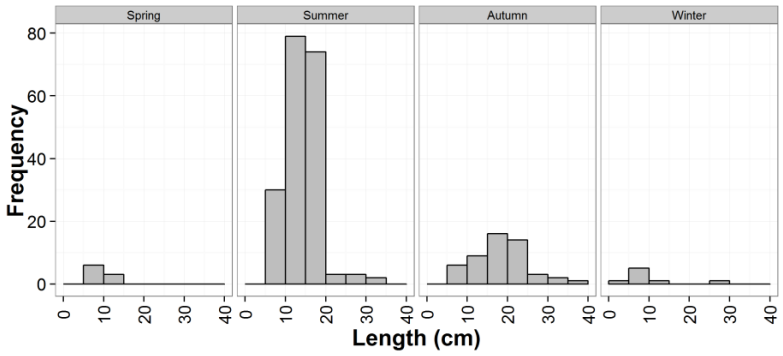


I) West coast – south

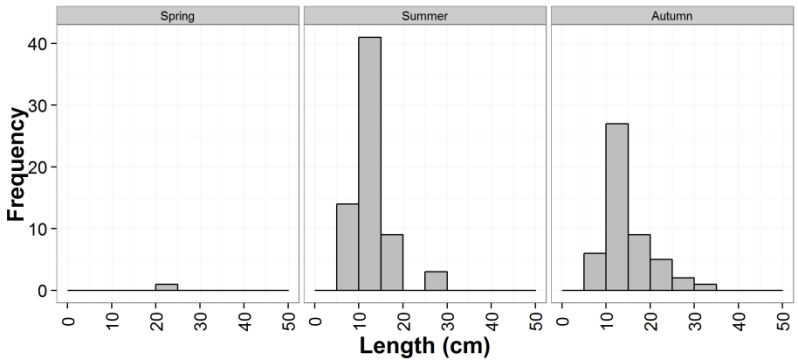


Dab

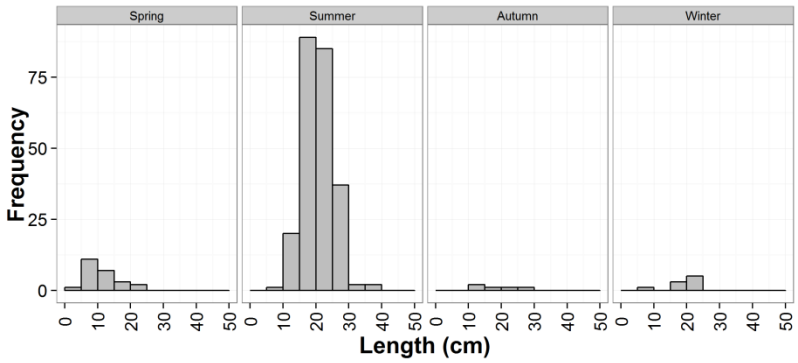
A) England



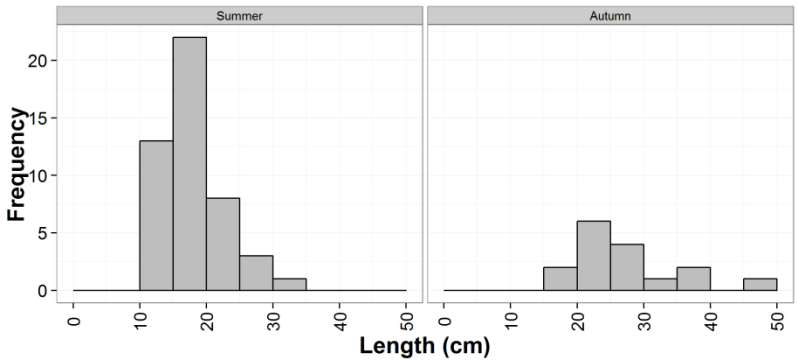
B) southeast Scotland



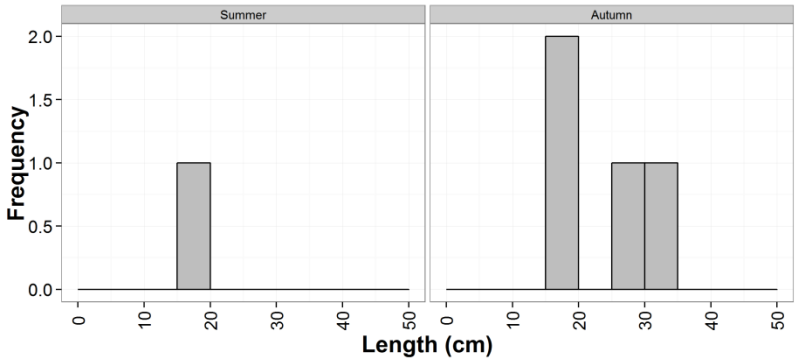
C) Moray Firth



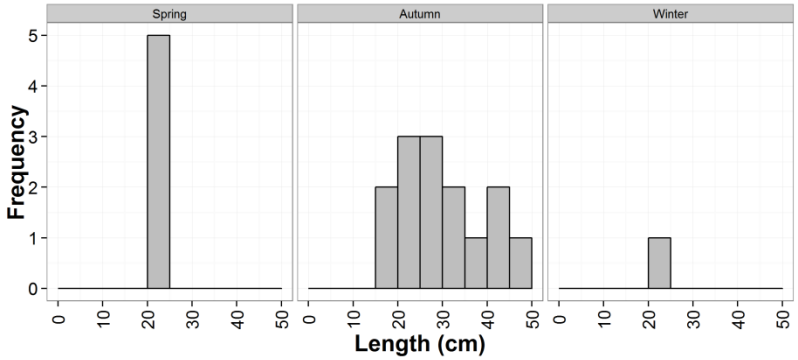
D) Orkney



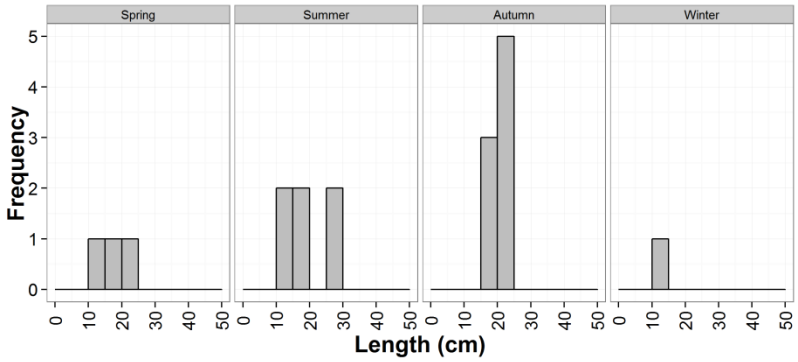
E) Shetland



F) West coast – central

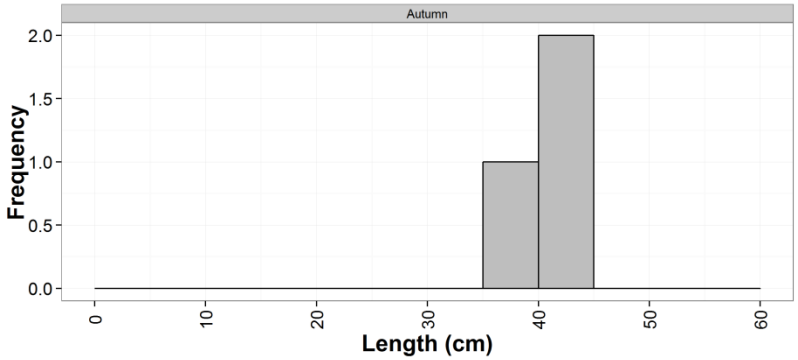


G) West coast – south

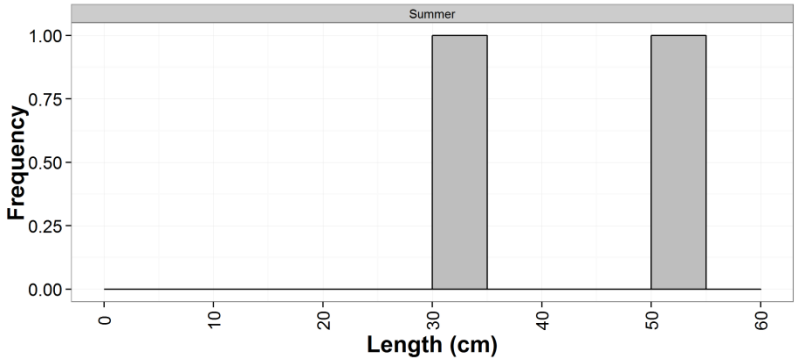


Mackerel (minimum landing size: 20cm west coast Scotland; 30cm North Sea)

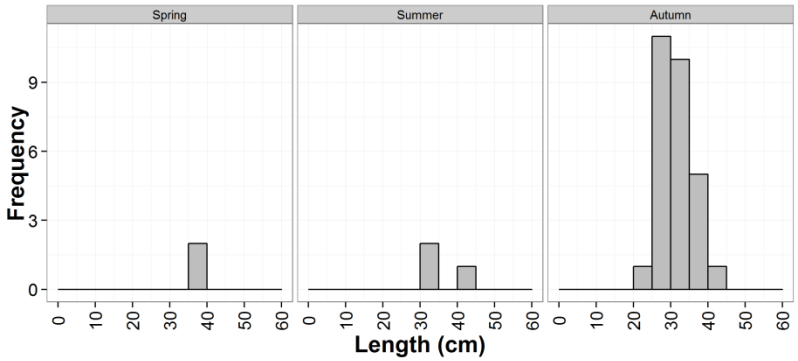
A) southeast Scotland



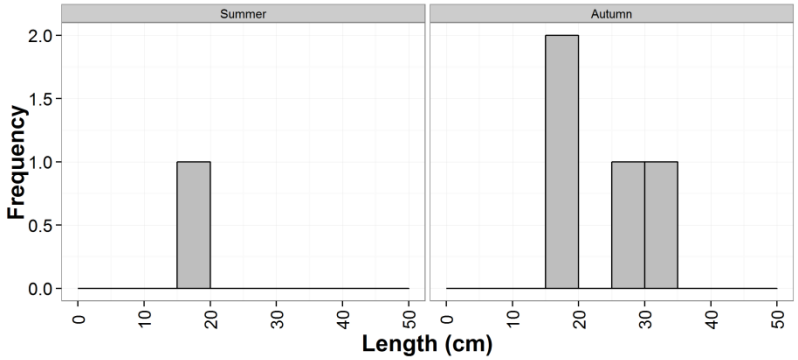
B) Moray Firth



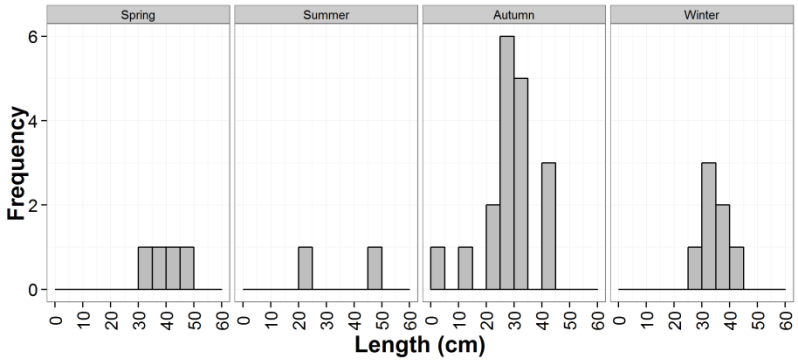
C) Orkney



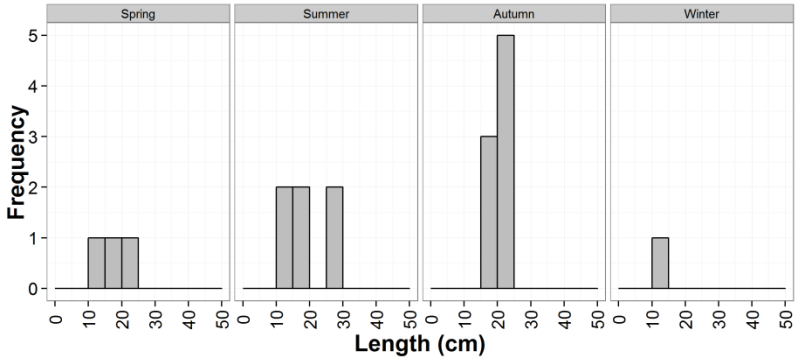
D) Shetland



E) West coast – central

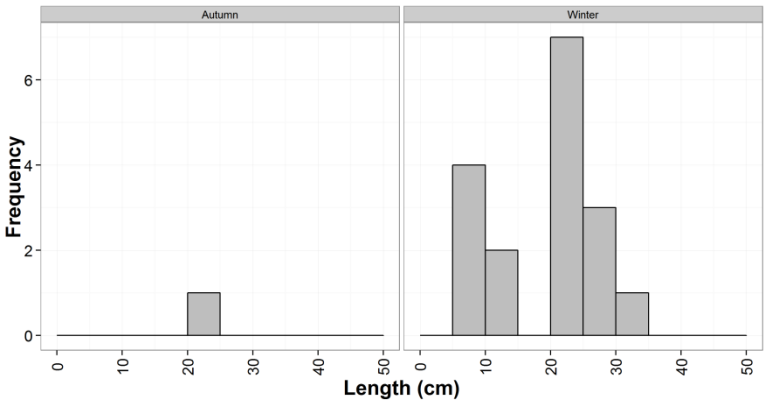


F) West coast – south

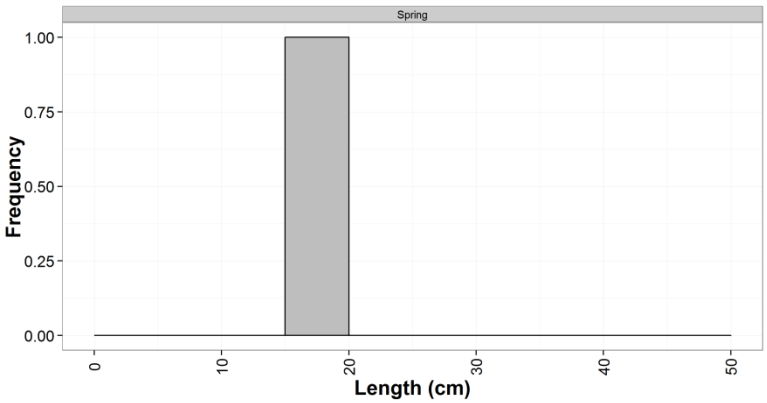


Herring (minimum landing size: 20cm)

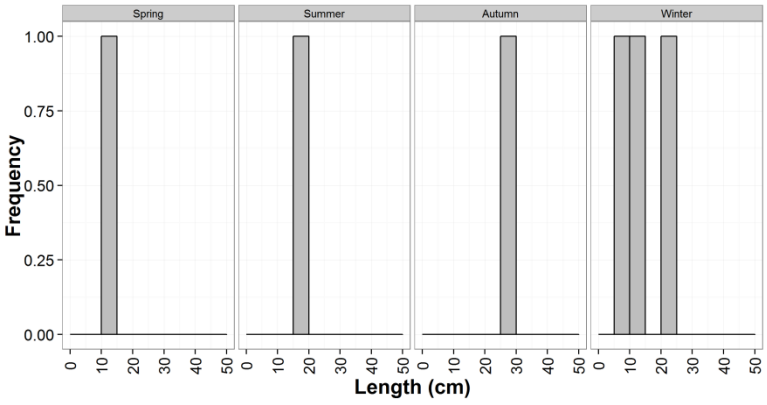
A) England



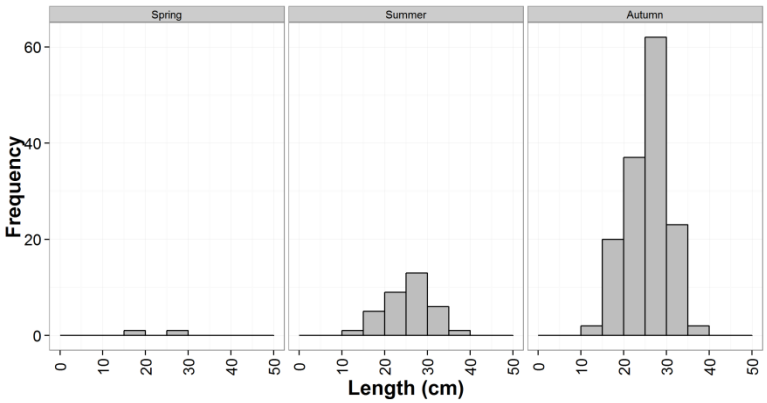
B) southeast Scotland



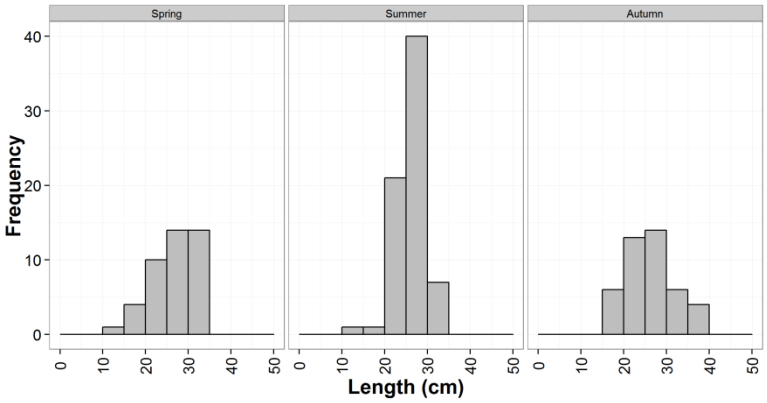
C) Moray Firth



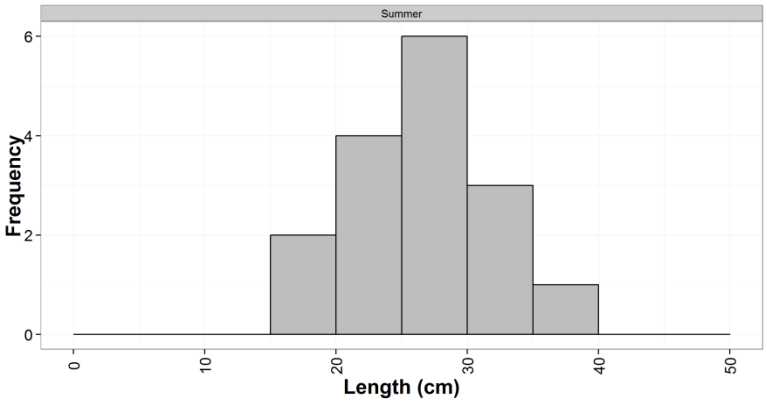
D) Orkney



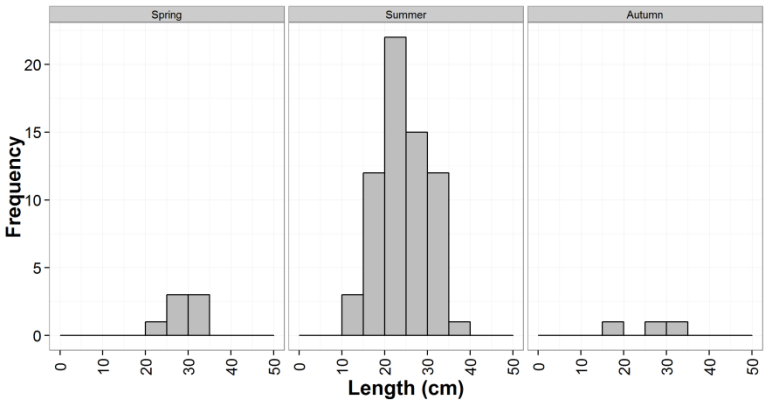
E) Shetland



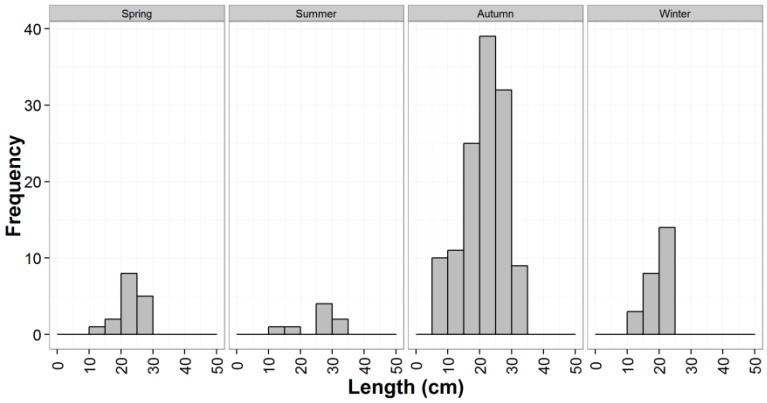
F) Outer Hebrides



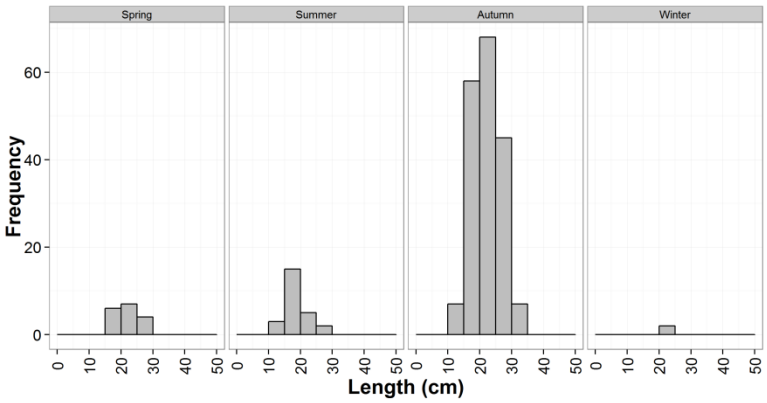
G) West coast – north



H) West coast – central

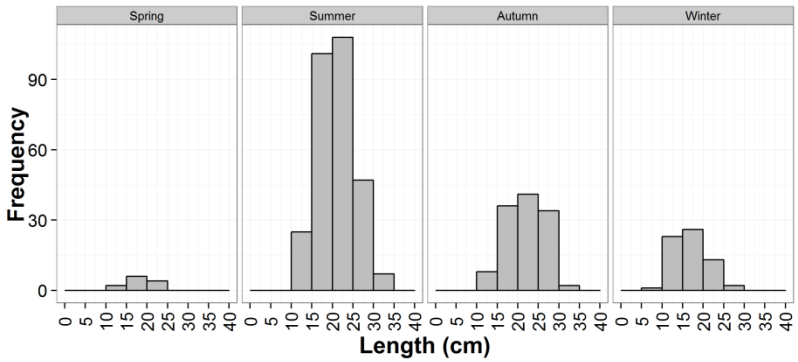


I) West coast – south

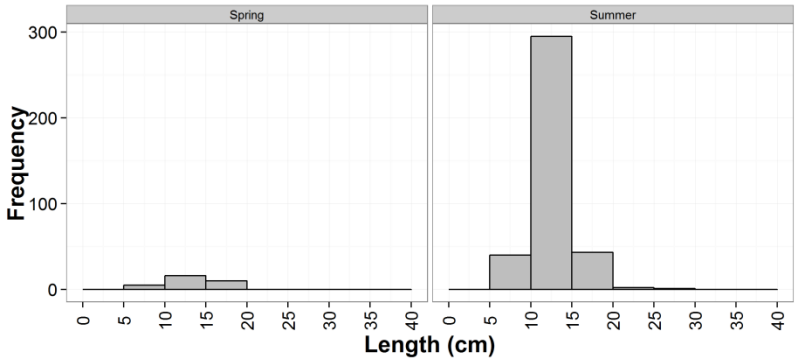


Sandeel

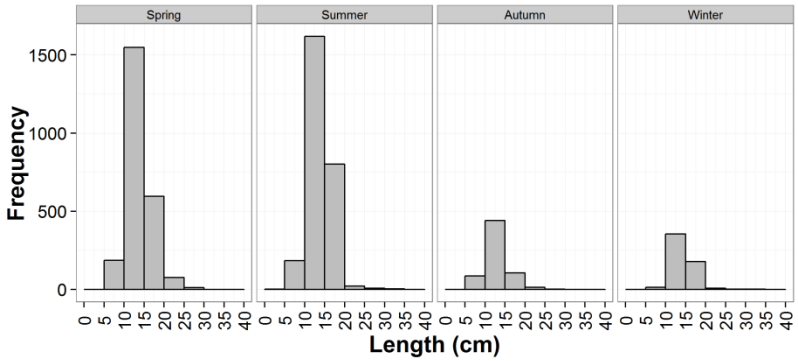
A) England



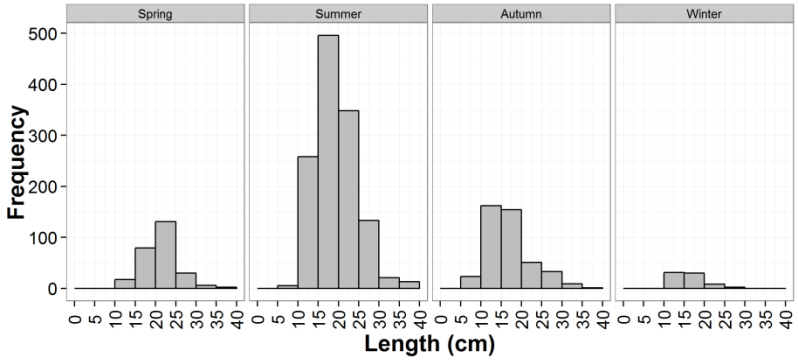
B) southeast Scotland



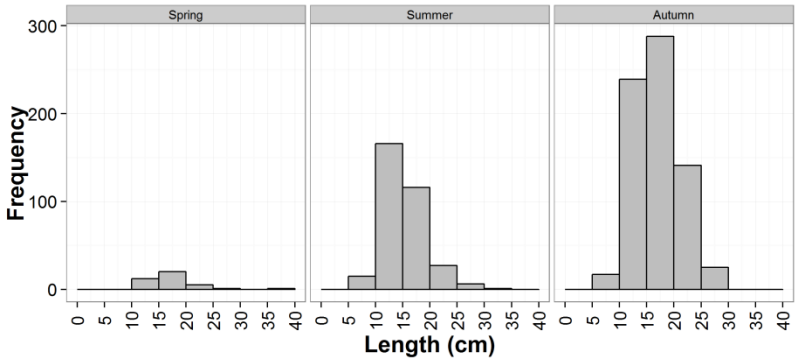
C) Moray Firth



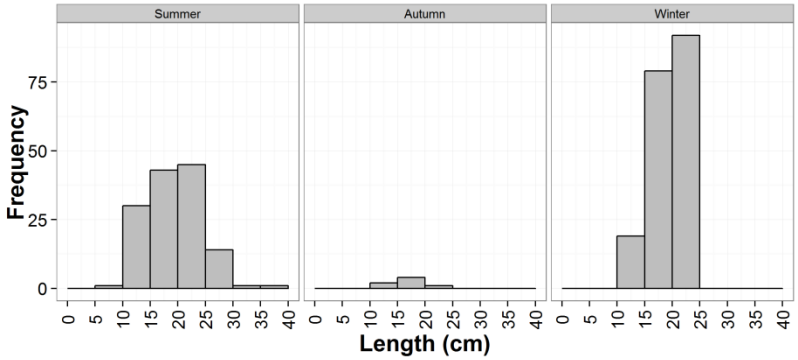
D) Orkney



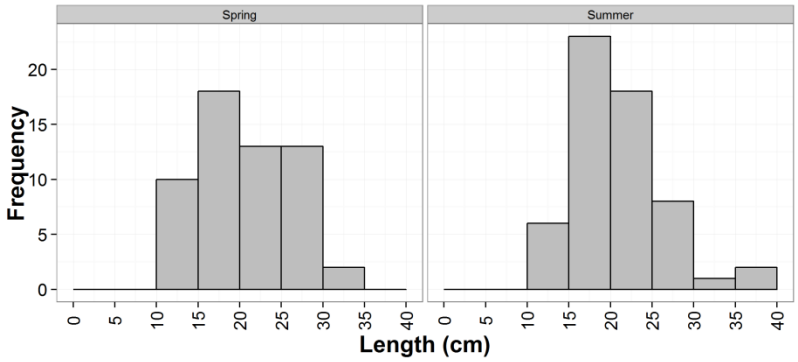
E) Shetland



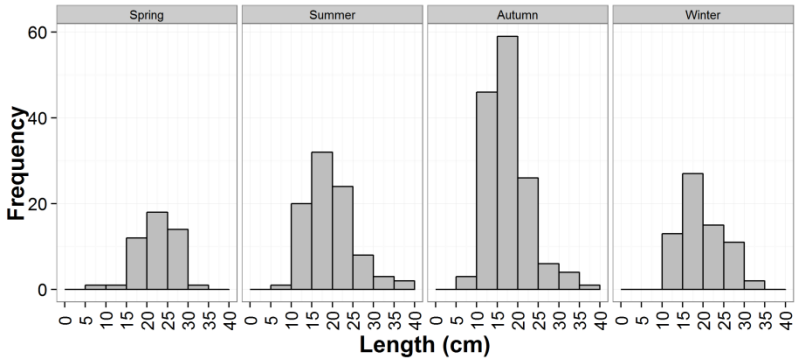
F) Outer Hebrides



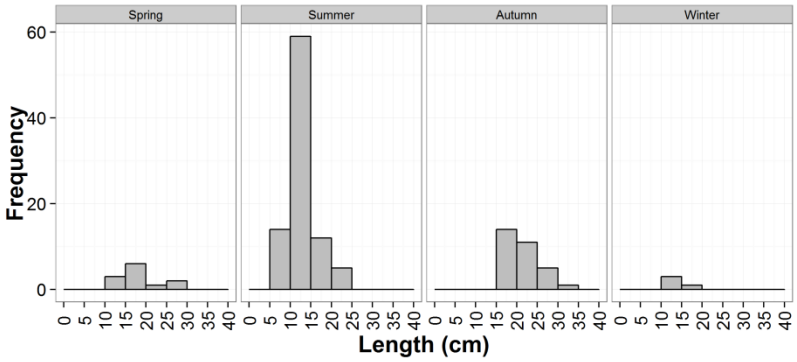
G) West coast – north



H) West coast – central

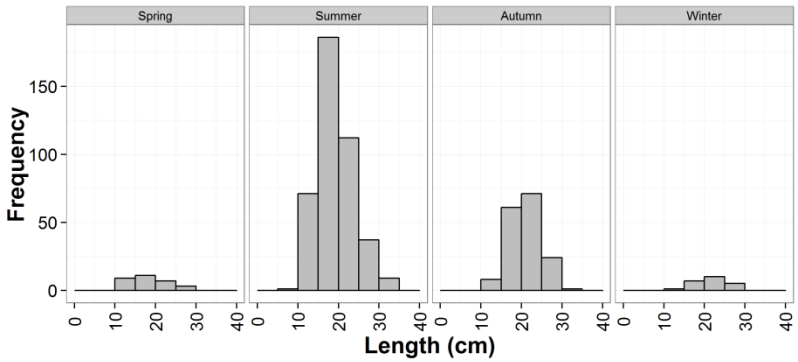


I) West coast – south

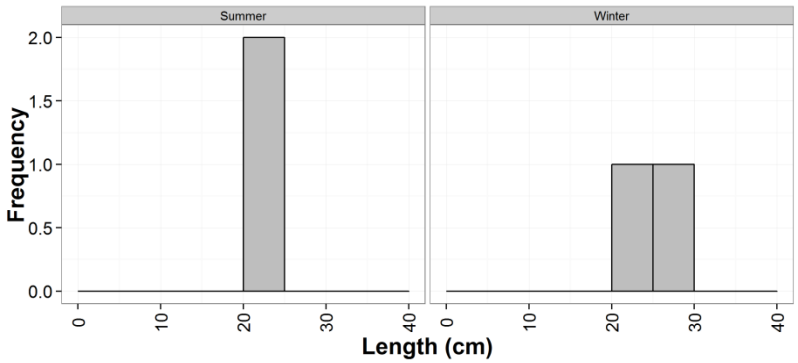


Dragonet

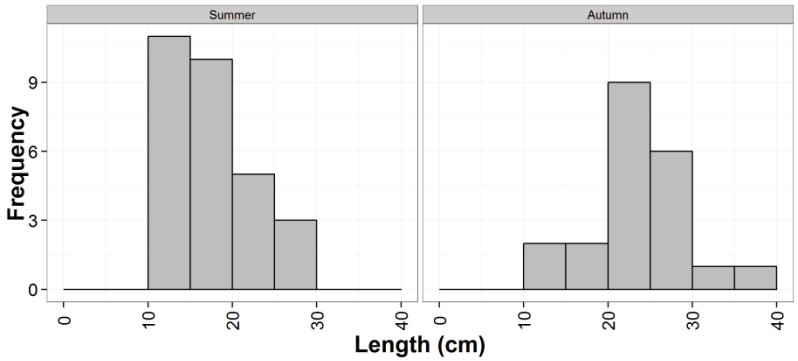
A) England



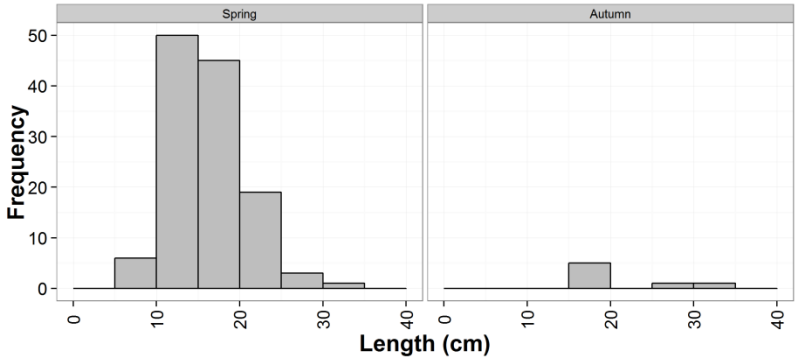
B) southeast Scotland



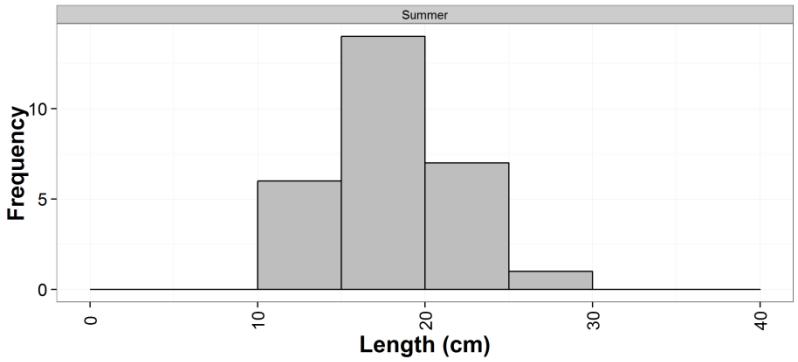
C) Orkney



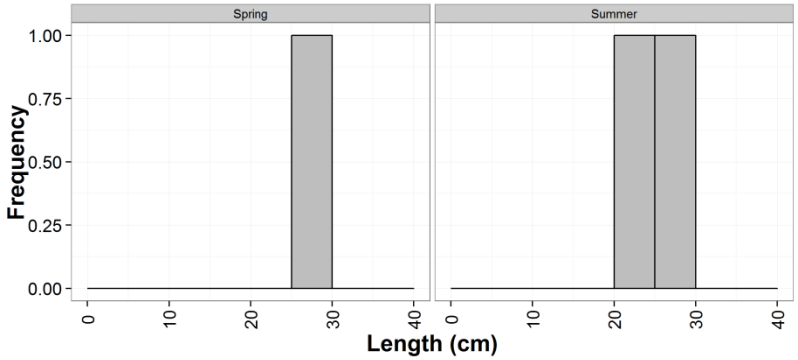
D) Shetland



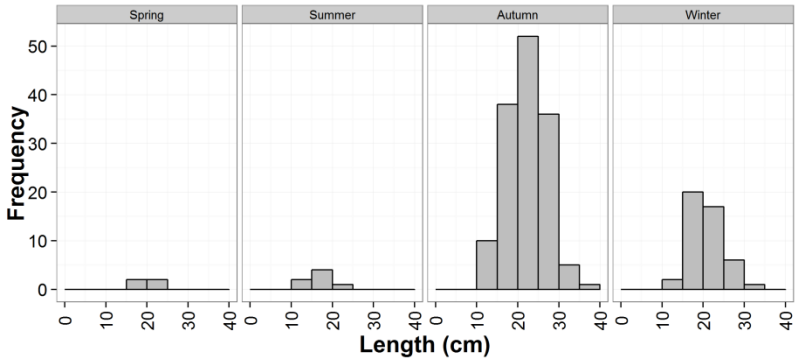
E) Outer Hebrides



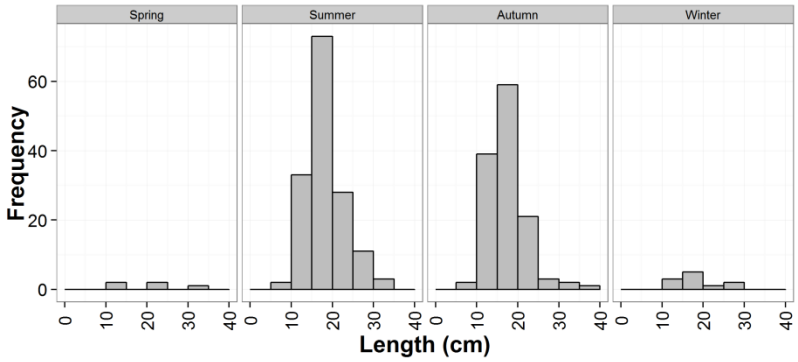
F) West coast – north



G) West coast – central



H) West coast – south



8.2 Appendix 2: Estimated 95% confidence intervals of estimated diet composition, expressed as the percentage of each prey type in the diet by weight, for the main prey species.

See Table 5 for point estimates. Prey species listed are those that contributed >2% in any season.

A) The Wash

Species	Summer	Autumn	Winter	Spring
Whiting	0.4-2.7	16.4-44.4	12.5-33.3	0-8.6
Cod	0-6.5	0-1.0	0-11.4	
Sandeel	6.8-42.8	1.4-16.9	1.3-15.0	0.7-10.3
Dover sole	2.4-10.5	1.2-23.5	0.3-4.3	10.9-61.9
Plaice	2.5-18.5	3.2-20.8	0.1-5.6	0.1-1.2
Lemon sole	0.3-5.6	0.7-16.6	0-17.3	
Unid. flatfish	1.0-4.1	2.2-9.3	0.1-1.7	0-0.4
Dab	2.0-8.8	1.4-7.4	0-2.7	0-1.6
Flounder	1.1-7.9	0-3.6		
Dragonet	26.0-59.1	10.9-33	2.5-19.5	1.9-55.0
Goby	1.8-7.1	0.1-1.4	1.8-14.1	5.0-30.8
Bullrout		0-5.7	0.8-35.2	0-37.4
Sea Scorpion	0-0.7	0-1.7	0.6-20.5	
Sprat			1.8-17.5	0-8.7
Herring		0-0.3	0-19.4	
Loligo		0-3.8	0-12.2	

B) southeast Scotland

Species	All seasons
Whiting	0.9-18.2
Cod	0.6-7.6
Saithe	0-10.8
Sandeel	3.1-42.7
Plaice	8.7-46.7
Dab	2.7-12.9
Flounder	1.1-12.4
Unid. flatfish	1.6-6.1
Goby	0-6.5
Sprat	0-14.2
Mackerel	0-13.1
Loligo	0-24.4

C) Moray Firth

Species	Summer	Autumn	Winter	Spring
Saithe	0-1.9	0.1-8.4	0-31.6	
Sandeel	36.4-77.5	42.3-95.6	38.9-84.5	70.8-93.3
Dab	5.3-28.1	0.1-3.6	0.7-7.4	0-1.7
Plaice	4.4-19.3	0.5-4.0	0.2-2.6	0.2-1.4
Flounder	0.2-3.0	0-2.8	1.0-16.0	1.5-14.9
Unid. flatfish	1.1-6.7	0-2.4	0.3-3.4	0.5-4.4
Dragonet	0-0.9		0-7.6	
Bullrout	0.3-11.4	0-22.6		0-1.1
Sprat			1.9-22.1	0.8-7.3
Unid. Salmonid	0-2.8	0-19.9		
Loligo	0-8.3	0-3.7		

D) Orkney

Species	Summer	Autumn	Spring
Cod	11.6-37.5	16.3-43.4	0-17.7
Saithe	0.3-15.3	0.2-16.9	1.4-79.7
Haddock	0-2.1	0.9-7.3	0-2.6
Ling	0.6-5.6	0-11.5	
Sandeel	29.6-70.9	5.9-31.5	14.3-89.5
Dab	0.3-3.1	0.2-11.6	
Plaice	0.7-5.6	0.3-2.5	
Flounder	0-7.7		
Dragonet	0.4-3	0.5-9.0	
Sea Scorpion	0-10.1	0-0.6	
Herring	0.3-9.1	11.4-36.5	0-2.7
Mackerel	0-4.2	2.1-23.2	0-9.6

E) Shetland

Species	Summer	Autumn	Spring
Saithe	0.5-21.2	4.0-66.5	0.4-61.0
Ling	1.7-32.6	0-2.0	0-7.0
Rockling	0-3.5		0-28.3
3-bearded rockling			0-8.5
Norway pout	3.4-16.3	0-1.5	0.2-12.0
Poor cod	0.5-3.6	1.2-12.2	0.1-1.8
Sandeel	12.9-58.3	9.2-55.1	0.3-21.4
Lemon sole		0-9.5	
Plaice	0-7.2	0-0.5	
Dragonet		0-2.7	6.9-53.7
Herring	13.2-52.6	2.2-19.2	7.5-53.2
Mackerel	0-4.2	2.2-27.9	0-8.7
Garfish		1.7-27.3	

F) Outer Hebrides

Species	Summer
Cod	1.0-7.9
Rockling	0-13.5
Ling	0-9.7
Saithe	0-17.1
Whiting	1.0-3.8
Norway pout	9.1-30.7
Poor cod	1.8-7.7
Sandeel	1.5-32.8
Dragonet	0-10.4
Unid. Cottidae	1.6-35.0
Mackerel	3.2-34.7
Herring	1.3-10.2
Horse mackerel	0.3-7.2
Eledone	0.4-10.7

G) West coast - north

Species	Summer	Spring
Ling	2.5-17.6	0.8-33.7
Cod	5.2-22.6	0-12.9
Saithe	0.7-55.1	0.6-40.2
Whiting	1.7-18.3	0.5-4.7
Blue whiting	2.2-14.8	0-1.7
Rockling	0-0.1	0-16.7
Haddock	0-2.6	0.1-5.9
Norway pout	4.6-15.5	6.1-31.0
Poor cod	3.7-15.0	2.7-11.7
Norway pout or Poor cod	0.9-4.5	
Sandeel	0.6-6.7	1.8-26.2
Mackerel	0.7-18.8	1.8-36.2
Herring	4.2-20.3	1.0-12.1
Loligo	0-1.7	0-16.2

H) West coast - central

Species	Summer	Autumn	Winter	Spring
Blue whiting	5.2-34.7	0-2.0	6.0-28.7	5.3-39.1
Whiting	7.5-25.0	0.7-2.8	2.7-15.4	0.2-2.4
Haddock	0.1-1.3	1.2-4.8	0.3-5.2	2.9-19.5
Saithe		0.1-14.5	0.4-39.3	0.8-35.7
Cod	0-5.5	1.2-7.6	0.2-13.4	0-18.0
Ling	0-3.9	0-4.0	0.5-19.1	0-8.7
Saithe or Pollock		0-2.4	0-30.9	
Unid. gadid	1.9-8.7	0.1-1.1	0.9-5.0	0.4-2.6
Hake	0.4-5.7		0-3.2	0-3.6
Poor cod	3.1-15.4	1.2-6.5	4.8-19.7	1.2-6.0
Norway pout	4.7-19.7	0.7-2.8	1.5-8.8	0.2-5.8
Sandeel	2.2-13.7	0.7-18.1	0.9-11.8	1.1-9.1
Dab		0.3-8.7	0-0.6	0-1.7
Lemon sole	0-1.9	0-0.7		0.4-6.9
Plaice	0-0.7	0.5-4.7		0-2.0
Dragonet	0.2-2.0	4.1-45.0	1.5-36.6	0-2.1
Unid. Cottidae	0-44.8	0.2-5.3		
Mackerel	0-22.0	8.6-57.3	0-0.9	7.0-55.3
Herring	0.3-6.4	3.9-17.5	0-8.7	0.4-7.8
Horse mackerel		1.7-7.7	0.3-2.9	0-0.3
Eledone		0-1.6		0-5.9

I) West coast - south

Species	Summer	Autumn	Winter	Spring
Haddock	10.0-23.3	13.5-32.8	3.7-24.0	15.1-39.9
Whiting	16.0-31.0	4.1-11.7	5.0-36.4	7.7-19.7
Cod	0.5-12.3	2.2-13.7	4.2-40.5	7.7-39.1
Saithe	0-7.4	0.1-8.9	0.5-61.9	0.1-21.2
Unid. gadid	3.6-12.4	0.5-4.9	0.7-6.5	1.9-8.9
Ling	0-2.8	0-4.8	0-22.2	
Blue whiting	2.2-8.6	0-0.6	0-2.4	1.4-6.4
Rockling	0-0.6	0.3-7.9		0-0.3
Poor cod	2.3-6.3	2.1-9.5	2.6-12.0	2.1-8.5
Norway pout	2.5-5.6	0-0.2	0.1-1.4	1.6-5.1
Witch	0.1-2.4	0.1-2.6		0.5-4.6
Dragonet	3.7-25.8	5.1-21.9	0-19.1	0-5.1
Herring	0.3-4.2	9.8-30.3	0-8.1	0.8-8.1
Mackerel	2.8-28.1	1.2-18.1	0-10.2	0-13.1
Eledone	0-6.9	0-3.8		

8.3 Appendix 3: Estimated 95% confidence intervals of estimated diet composition, expressed as the percentage of each prey type in the diet by weight, for prey groups.

See Table 6 for point estimates.

A) The Wash

Prey type	Summer	Autumn	Winter	Spring
Gadid	0.6-8.7	16.6-44.6	14.6-39.7	0-8.6
Trisopterus	0-3.5	0-0.7	0-4.5	
Sandeel	6.8-42.8	1.4-16.9	1.3-15.0	0.7-10.3
Flatfish	16.5-40.1	21.2-51.4	4.6-24.0	12.5-62.6
Sandy benthic	29.1-63.5	11.4-33.9	7.2-26.1	14.4-72.1
Scorpion fish	0-0.9	0.3-6.4	4.7-41.5	0-37.4
Pelagic	0-0.4	0-0.4	3.7-29.8	0-8.7
Salmonid				
Cephalopod	0-0.1	0-6.7	0-12.2	0
Other	0-1.3	0-1.2	0-0.1	0-0.5

B) southeast Scotland

Prey type	All seasons
Gadid	5.6-26.4
Trisopterus	
Sandeel	3.1-42.7
Flatfish	20.7-64.6
Sandy benthic	0.1-8.2
Scorpion fish	0-3.5
Pelagic	1.7-21.5
Salmonid	0-2.2
Cephalopod	0-24.4
Other	0-2.6

C) Moray Firth

Prey type	Summer	Autumn	Winter	Spring
Gadid	1.1-5.0	1.2-12.8	1.6-33.6	0.3-8.6
Trisopterus	0-0.1		0-1.5	
Sandeel	36.4-77.5	42.3-95.6	38.9-84.5	70.8-93.3
Flatfish	14.0-51.0	0.9-10.3	4.1-24.3	3.5-20.9
Sandy benthic	0-0.9	0-1.3	0-7.7	
Scorpion fish	0.3-11.4	0-22.6		0-1.1
Pelagic	0-5.2	0-4.9	2.3-22.9	0.8-7.3
Salmonid	0-2.8	0-19.9		
Cephalopod	0-8.3	0-3.7		
Other	0-0.2	0-2.1	0-1.1	0-0.3

D) Orkney

Prey type	Summer	Autumn	Spring
Gadid	16.9-48.8	25.8-56.5	5.4-81.9
Trisopterus	0.3-1.8	0.1-0.4	0-6.6
Sandeel	29.6-70.9	5.9-31.5	14.3-89.5
Flatfish	2.3-15.7	1.4-14.0	
Sandy benthic	0.5-3.0	0.5-9.0	0-1.6
Scorpion fish	0.5-11.3	0-0.6	0-0.7
Pelagic	0.8-11.2	17.6-47.4	0-10.4
Salmonid			
Cephalopod	0-1.0	0-4.1	0-5.1
Other	0-0.8	0-2.6	0-1.0

E) Shetland

Prey type	Summer	Autumn	Spring
Gadid	6.0-41.5	8.5-68.5	5.1-69.3
Trisopterus	4.9-17.9	1.5-12.9	0.6-14.4
Sandeel	12.9-58.3	9.2-55.1	0.3-21.4
Flatfish	0-7.6	0.6-10.7	
Sandy benthic		0-2.7	6.9-53.7
Scorpion fish			
Pelagic	13.8-54.0	6.4-40.1	7.5-57.8
Salmonid			
Cephalopod	0-2.0	0-0.7	0-4.4
Other	0-0	1.7-27.3	0-0.3

F) Outer Hebrides

Prey type	Summer
Gadid	7.3-34.4
Trisopterus	12.6-36.6
Sandeel	1.5-32.8
Flatfish	0.1-5.6
Sandy benthic	0-10.4
Scorpion fish	1.6-35.0
Pelagic	8.3-41.7
Salmonid	
Cephalopod	0.4-10.7
Other	0-0.8

G) West coast - north

Prey type	Summer	Spring
Gadid	37.3-77.5	16.6-65.8
Trisopterus	9.9-31.6	10.6-38.0
Sandeel	0.6-6.7	1.8-26.2
Flatfish	0-5.6	0.1-0.7
Sandy benthic	0-1.7	0-3.1
Scorpion fish		
Pelagic	7.7-33.1	6.9-41.3
Salmonid	0-1.2	
Cephalopod	0.1-4.7	0-16.2
Other		0-0.1

H) West coast - central

Prey type	Summer	Autumn	Winter	Spring
Gadid	23.6-62.1	6.5-26.1	37.4-74.8	28.3-74.0
Trisopterus	9.8-31.0	2.3-8.9	7.0-27.7	2.0-10.4
Sandeel	2.2-13.7	0.7-18.1	0.9-11.8	1.1-9.1
Flatfish	0.2-3.3	1.2-15.5	0.7-4.6	1.6-11.1
Sandy benthic	0.2-2.0	4.1-45.0	1.6-36.6	0-2.2
Scorpion fish	1.0-45.9	0.2-5.3	0.1-3.9	
Pelagic	2.2-24.3	21.7-67.9	0.8-11.7	9.6-58.7
Salmonid				
Cephalopod	0-4.5	0.1-2.1	0-1.4	0.6-10.0
Other	0-0.9			

I) West coast - south

Prey type	Summer	Autumn	Winter	Spring
Gadid	43.6-71.6	33.5-58.6	59.9-91.6	62.9-84.5
Trisopterus	5.4-11.9	2.7-10.2	2.9-13.3	4.0-13.8
Sandeel	0.3-2.0	0.3-3.0	0-0.9	0.1-2.5
Flatfish	1.1-4.8	2.4-8.3	0-3.7	2.1-8.2
Sandy benthic	3.7-25.8	5.3-22.0	0.1-19.2	0.1-5.3
Scorpion fish	0-0.2	0-4.1	0-6.2	0-3.9
Pelagic	4.9-30.6	14.2-40.7	0-14.1	2.6-17.5
Salmonid				
Cephalopod	0-6.9	0.3-4.6		
Other	0-0.5	0-3.1		

8.4 Appendix 4: Estimated 95% confidence intervals of estimated diet composition.

Estimated 95% confidence intervals are expressed as the percentage of each prey type in the diet by weight, for the main prey species consumed by male (M) and female (F) harbour seals (see Table 9 for point estimates). Prey species listed are those that contributed >2% in any season.

A) The Wash

	Summer		Autumn		Winter		Spring		All seasons	
Species	**M**	**F**	**M**	**F**	**M**	**F**	**M**	**F**	**M**	**F**
Cod	0-1.4		0-1.1		0-16.7		0-3.9		0.3-4.8	
Whiting	1.2-11.7	0.1-2.4	14.1-43.4	6.4-34.5	12.0-43.1	1.2-14	0.7-6	1-14.6	10.1-20.9	4.2-12.5
Sandeel	10.2-54.2	3.8-51.2	1.5-16.6	2.7-27.6	0.4-15.2	0.4-16.2	0.3-12.6	0.9-8.9	5.5-17.8	5.1-19
Plaice	2.0-17.9	3.2-13.5	4.4-25.9	0.9-6.5	0.1-7.3	0-0.4	0-11.3	0.2-1.0	3.1-10.4	1.5-4.4
Lemon sole	0.4-7.1	0-2.3	0.7-13.0	0.7-16.5	0-25.3	0-22.2	0-1.6	0-8.8	1.3-8.9	0.9-9.1
UNID flatfish	0.3-2.6	0.5-3.7	2.3-8.9	0.4-6.0	0-1.1	0-0.3	0-1.2	0.1-1.1	1.0-2.7	0.5-2.1
Dover sole	1.3-7.0	2.0-16.6	2.0-19.2	0-1.8	0-4.8	0-3.2	1.7-62.2	5.2-24.4	2.9-18.9	3.0-9.2
Flounder	0-0.7	1.9-16.2	0-2.3	0-5.8					0-0.6	0.7-4.6
Dab	1.3-7.3	1.9-10.3	2.5-10.7	1.5-10.2	0-3.7	0-0.2		0.1-1.3	1.4-4.2	1.4-4.5
Brill	0-5.8	0-0.5	0.2-2.8	0-5.7					0.2-1.8	0-1.5
Dragonet	20.7-58.5	17.1-56.6	13.5-35.1	6.2-28.8	2.2-22.4	0-29.4	2.2-38.1	11.5-55.1	14.3-29.7	15.3-33.8
Goby	0-0.4	3.2-14.1	0-0.4	0.7-5.1	0.1-4.8	1.5-36.4	0-0.2	8.4-35.5	0.1-1.3	5.8-17.7
Hooknose	0-0.2			0-17.4		0-1.7	0-1.1	0-2.3	0-0.3	0.2-4.7
Bullrout	0-2.1		0-4.5	0-32.1	0.9-52.4	0-21.0	0.8-86.7	0-24.8	6.1-32.4	0.4-13.6
Sea Scorpion	0-2.3		0-2.4	0-24.1		2.6-46.3	0-11.4	0-6.1	0.1-3.1	1.3-14.4
Mackerel				0-9.6						0-2.4
Herring	0-1.1		0-0.5		0-2.0	0-50.5	0-3.7	0.8-17.3	0.1-1.2	0.5-14.5
Sprat					0.1-9.7	2.2-46.9		0-5.0	0-2.4	0.7-12.0
Eledone				0-13.2						0-3.3
Loligo	0-1.9		0-2.7	0-0	0-16.3				0.2-4.5	

B) Moray Firth

	Summer		Autumn/Winter		Spring		All seasons	
species	**M**	**F**	**M**	**F**	**M**	**F**	**M**	**F**
Saithe	0-3.8	0-1.3	0-27.7	0.1-9.5	0-21.2	0.1-4	0-14.9	0.2-5.0
Sandeel	20.9-69	31.1-86.1	45.3-95	34.7-89.8	72.6-98.5	56.2-94.4	57.1-85.3	51.0-84.4
Plaice	4.8-21.5	2.8-27.8	0-4.7	0.3-3.3	0-0.9	0.1-1.7	1.7-6.7	1.4-7.8
UNID flatfish	1.5-13.2	0.4-7.3	0-6.6	0.1-2.9	0.1-3.9	0.2-7.1	0.9-5.4	0.6-3.5
Flounder	0-3.4	0-5.1		0.6-12.3	0-6.9	0.9-29.1	0-2.1	1.7-11.0
Dab	6.4-39.9	2.5-30.0	0.4-11.4	0-3.9		0-3.4	2.6-12.8	1.4-8.6
Bullrout		0-17.1		0-19.0		0-0.9		0.1-11.6
Sprat			0.2-17.7	0.3-17.2	0-1.3	0.4-4.1	0.2-9	0.4-9.2
UNID Salmonid	0-7.6			0-17.4			0-1.9	0-8.7
Loligo	0-20.8	0-0.3		0-2.6			0-5.2	0-1.3

C) West coast - central

Species	Summer M	Autumn M	Winter M	Spring M	All seasons M	All seasons F
Cod		0.9-6.7		0-6.9	0.3-2.9	0-32.0
Whiting	4.2-31.5	0.7-3.0	2.1-19.2	0.1-1.3	3.0-11.0	0.8-14.7
Haddock	0.1-2	0.8-4.0	0-1.4	1.8-22.7	1.2-6.4	0-3.8
Saithe		0.2-17.7	0.2-40.0	0.8-45.2	0.9-16.7	0-9.2
Ling	0-7.4	0-5.0	0-19.5	0-11.8	0.9-7.8	0-17.4
UNID gadid	1.2-10.2	0.1-1.1	0.4-4.4	0.2-2.2	1.0-3.5	0-4.6
Saithe or Pollock		0-3.4	0-39.1		0-9.8	
Blue whiting	7.2-63.7	0-2.0	5.3-29.8	5.9-44.4	9.6-28.1	0.4-13.2
Poor cod	1.0-7.2	1.2-7.2	5.1-26.3	0.8-5.7	3.1-9.3	0.6-16.9
Norway pout	0.9-5.6	0.5-2.4	1-9.9	0.1-7.5	1.3-4.7	0.4-6.3
Sandeel	0.5-7.7	0.8-22.4	0.2-6.6	0.7-9.1	1.7-8.1	0.1-14.8
Plaice		0.4-5.8			0.1-1.5	
Lemon sole	0-2.0	0-0.9		0.3-8.8	0.2-2.4	
Dragonet	0-0.2	3.4-51.6	1.1-50.0	0-3.0	2.6-21.5	0.6-42.4
UNID Cottidae	0-58.6	0-6.4			0.1-15	0-8.4
Gurnard			0-1.8		0-0.5	0-7.7
Mackerel	0-29.9	6.2-47.0		6.1-56.3	6.3-24.9	0-74.9
Herring	0-7.4	4.4-21.4	0-14.8	0.2-6.6	2.2-8.3	0-14.6
Horse mackerel		2.2-10.2	0-2.7	0-0.4	0.7-2.8	0-4.8
Eledone	0-6.5	0-2.0		0-8.5	0.3-3.1	
Loligo		0-1.5		0-7.7	0-1.9	0-7.6

D) West coast - south

Species	Summer M	Autumn M	Winter M	Spring M	All seasons M	All seasons F
Cod	1.1-19.9	2.0-16.5		10.5-43.9	5.8-16.4	0.3-4.1
Whiting	14.3-30.7	4.6-14.9	0-35.8	6.1-16.8	8.9-19.6	6.5-40.2
Haddock	9.4-24.2	17.5-43.1	0-61.7	10.8-38.8	13.8-33	1.3-13.2
Saithe	0-1.6	0-9.3			0-2.4	0-14.7
Ling	0-5.2	0-6.2	0-62.6	0-15.4	0.7-18.5	
Rockling	0-1.2	0-10.8		0-0.7	0.2-2.9	0-1.9
UNID gadid	2.8-13.9		0-13.6	1.3-6.7	1.7-6.5	2.7-15.6
Blue whiting	2.0-12.0		0-3.4	2.1-11.4	1.6-5.4	0.7-4.0
Poor cod	1.7-4.4	0.3-2.6	0.4-21.3	0.5-2.6	1.3-6.8	5.0-21.8
Norway pout	2.3-5.2	0-0.1	0-4.6	1.3-4.8	1.2-2.9	0.9-11.3
Sandeel	0.1-0.9	0.3-5.5	0-0.7	0.5-5.5	0.5-2.4	0-2.2
Lemon sole	0-0.8	0.2-3.6	0-11.9	0-1.0	0.2-3.3	
Witch	0-3.5	0-1.1		0.8-6.5	0.5-2.1	0-6.1
Dragonet	0.8-31.5	2.5-13.3		0-13.1	2.6-11.6	1.4-19.1
Bullrout						0-11.5
Gurnard		0-0.9	0-22.2		0-5.6	
Mackerel	1.0-24.0	0-21.2	0-59.8	0-7.6	1.8-19.7	0-11.5
Herring	0-2.0	8.1-35.7		1.0-9.4	3.1-10.3	1.3-24.8
Argentine	0-1.1	0-1.1		0-7.8	0.1-2.1	0-1.5
Eledone	0-13.7	0-0.7			0-3.5	0-11.4
Eelpout		0.1-2.1			0-0	0-7.5

8.5 Appendix 5: Estimated 95% confidence intervals of estimated diet composition for the main prey groups.

Estimated 95% confidence intervals of estimated diet composition for the main prey groups consumed by male (M) and female (F) harbour seals (see Table 10 for point estimates).

A) The Wash

	Summer		Autumn		95% CL Winter		Spring		All Seasons	
Prey type	**M**	**F**	**M**	**F**	**M**	**F**	**M**	**F**	**M**	**F**
Gadid	1.5-	0.1-2.4	14.5-44	6.4-34.5	14.8-51	1.2-14	1.3-7.6	1-14.6	11.5-	4.2-12.6
Trisopterus	0.1-1		0-0.2	0-1.6	0-7.4		0-0.7	0-0.5	0.1-2	0-0.4
Sandeel	9.9-57	3.8-51.2	1.5-16.6	2.7-27.6	0.4-15.2	0.4-16.2	0.3-12.6	0.9-8.9	5.4-18.5	5.1-19
Flatfish	12-	17.1-46	25.1-	10.3-	4.2-31.6	0-24.7	3.2-69.1	8.1-31.4	15.7-	12.7-
Sandy	20.1-	24.4-	13.8-	8-31.9	3.9-24.6	5.2-41.5	2.2-38.2	31.1-	14.5-	25.8-44
Scorpion fish	0.1-4.5	0-1.1	0.3-5.4	0.8-53.4	0.9-52.4	4-49.6	1.1-89.2	0.4-27.5	6.7-33.7	4.9-25.2
Pelagic	0-1.1	0-0.5	0-0.5	0-9.6	0.8-11.7	5.5-69.4	0-3.7	1.3-20.8	0.4-3.4	3.5-20.7
Salmonid										
Cephalopod	0-2	0-0.1	0-2.7	0-13.2	0-16.3				0.2-4.5	0-3.3
Other	0.1-3.6	0-1.9	0-0.9	0-0.2	0-0.1	0-0.1	0-0.1	0-0	0.1-1	0-0.5

B) Moray Firth

	Summer		Autumn/Winter		95% CL Spring		All Seasons	
Prey type	**M**	**F**	**M**	**F**	**M**	**F**	**M**	**F**
Gadid	0.9-9.4	0.7-4.2	0.7-32.1	1.3-13.5	0-21.6	0.2-4.7	1.6-17.8	1.4-7.6
Trisopterus			0-0.6	0-1.1		0-0.1	0-0.3	0-0.6
Sandeel	20.9-69	31.1-86.1	45.3-95	34.7-	72.6-	56.2-	57.1-85.3	51-84.4
Flatfish	17.9-66.6	7.8-60.8	1.3-18.3	2.6-18.4	0.6-11.5	3.2-38	7.2-23.1	8-25.5
Sandy	0-2.2		0-0.7	0-1.1			0-0.7	0-0.6
Scorpion fish		0-17.1		0-19		0-0.9		0.1-11.6
Pelagic	0-3.6		0.2-17.7	0.3-17.3	0-1.3	0.4-4.1	0.3-9.2	0.4-9.3
Salmonid	0-7.6			0-17.4			0-1.9	0-8.7
Cephalopod		0-0.3		0-2.6			0-5.2	0-1.3
Other	0-20.8	0-0.4		0-2.3	0-0	0-0.	0-0	0.1-1.2

C) West coast - central

	95% CL					
	Summer	Autumn	Winter	Spring	All Seasons	
Prey type	M	M	M	M	M	F
Gadid	27-83.9	6.3-28.4	24.5-73.4	25.8-75.9	30.7-53.8	8.4-60.5
Trisopterus	2.3-12.3	2.3-9.5	6.5-35.4	1.3-11.8	5-13.5	1.5-23
Sandeel	0.5-7.7	0.8-22.4	0.2-6.6	0.7-9.1	1.7-8.1	0.1-14.8
Flatfish	0-2.1	1.2-14.1	0.7-8.9	1.2-11.3	1.8-6.5	0-0.4
Sandy benthic	0-0.2	3.4-51.6	1.2-50	0-3	2.6-21.5	0.6-42.4
Scorpion fish	0-58.7	0-6.4	0-5.6		0.7-15.8	0-13.3
Pelagic	0.2-33	18.8-61.8	0.1-16.5	7.7-58.9	11.9-32.2	0.9-80.3
Salmonid						
Cephalopod	0-6.5	0.1-3.1	0-0	0.9-14.2	0.6-4.7	0-7.6
Other	0-0.2	0-0		0-0	0-0	

D) West coast - south

	95% CL					
	Summer	Autumn	Winter	Spring	All Seasons	
Prey type	M	M	M	M	M	F
Gadid	42.3-79	40-72.4	28.2-87.4	61.1-86	53.3-73.1	25.2-59.9
Trisopterus	4.6-9.3	0.4-2.7	0.9-24.5	2.2-6.8	2.9-9.2	8.6-29.1
Sandeel	0.1-0.9	0.3-5.5	0-0.7	0.5-5.5	0.5-2.4	0-2.2
Flatfish	0.6-5.3	1.8-8	0-11.9	1.5-9	1.9-6	0.3-12.9
Sandy benthic	0.8-31.6	2.5-13.3		0-13.1	2.6-11.6	1.9-19.5
Scorpion fish		0-0.9	0-22.2		0-5.6	0-13.8
Pelagic	1.7-25.6	12.5-45.9	0-59.8	2.9-17.1	7.7-26.7	2.5-30.9
Salmonid						
Cephalopod	0-13.7	0-2.1		0-0	0.1-3.7	0-12.2
Other	0-0.8	0-2.2			0-0.6	0-8.1

8.6 Appendix 6. Estimated 95% confidence intervals of estimated annual prey consumption (in tonnes) by harbour seals in 2010/11.

Point estimates are given in Table 12.

A: North Sea (ICES Subarea IV).

Prey species	Southern North Sea	southeast Scotland	Moray Firth	Orkney	Shetland	Total North Sea
Cod	15-332	4-59	8-42	685-1,720	8-101	866-1,942
Whiting	826-1,819	6-132	5-23	6-109	5-45	942-1,951
Haddock		0-10	1-16	33-203	0-45	48-234
Saithe		0-69	9-227	105-2,425	236-2,974	638-4,254
Ling				19-309	57-598	118-730
Poor cod	0-9		0-9	10-164	62-331	100-420
Norway pout				0-7	96-441	97-441
Sandeel	398-1,312	23-278	1,317-1,916	1,398-3,160	716-2,109	4,840-7,401
Plaice	220-831	54-367	40-154	24-122	1-109	531-1,213
Lemon sole	95-670	0-12	0-8	0-42	0-236	154-783
Unid. flatfish	104-313	9-47	22-76	3-58	0-28	192-421
Dover sole	543-1,789					543-1,789
Megrim			0-13			0-13
Mackerel		0-90	0-31	82-614	85-717	282-1,129
Herring	2-389	0-2	0-30	311-895	718-1,935	1,282-2,686
Sprat	52-433	0-93	22-145		0-14	140-554
Bullrout	96-1,247	0-25	5-174	1-45		177-1,345
Sea Scorpion	22-468			1-158		41-535
Dragonet	1,452-3,127	0-32	0-47	30-239	184-1,407	2,046-4,139

B. West of Scotland (ICES Division VIa). WC = west coast.

Prey species	Outer Hebrides	WC - north	WC - central	WC - south	Total West of Scotland
Cod	36-322	54-242	167-776	1,081-3,336	1,712-4,093
Whiting	34-158	27-174	347-949	1,607-3,374	2,297-4,214
Haddock	13-98	5-56	158-625	2,101-4,020	2,463-4,433
Saithe	0-656	25-635	81-1,648	178-3,182	632-4,140
Ling	0-390	56-375	96-669	26-967	427-1,703
Poor cod	63-299	61-181	376-919	539-1,110	1,307-2,151
Norway pout	332-1,268	113-346	252-702	199-438	1,212-2,327
Sandeel	57-1,260	30-219	232-829	63-229	643-2,000
Plaice	0-214	0-45	16-124	45-241	132-440
Lemon sole		0-2	18-182	16-210	57-320
Unid. flatfish	0-32		8-89	9-81	37-149
Dover sole			0-36	0-36	0-53
Megrim			0-30		0-30
Mackerel	120-1,188	37-305	671-2,116	389-1,662	1,836-3,993
Herring	50-395	63-219	183-647	542-1,498	1,141-2,259
Sprat				0-1	0-1
Bullrout			0-36	0-142	0-154
Sea Scorpion			0-19		0-19
Dragonet	0-438	0-28	245-1,678	694-2,072	1,351-3,349