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# Geographical variation in the diet within and between the harbour seals (*Phoca vitulina*), grey seals (*Halichoerus grypus*) and Baltic ringed seals (*Pusa hispida*) inhabiting the greater Baltic Sea.

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Delivered: 26/10 2015

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# Abstract

The aim of the study is to investigate if there is a geographical variation in the diet within and between the harbour seal (*Phoca vitulina*), the grey seal (*Halichoerus grypus*) and the Baltic ringed seal (*Pusa hispida*) within the greater Baltic Sea. I reanalysed data that I had gathered from previous surveys that have had collected scats and/or examined seals digestive tracts to find and identify otoliths and/or other hard parts from fish. The three seal species diets were then compared from various areas within the Danish Straits and the Baltic Sea, to examine if a geographical difference occurs. The results indicate that there is a geographical variation within the diet of harbour seals, even though some fish species e.g. cod (*Gadus morhua*) and sand lances (*Ammodytes sp.*) occurred as primary prey items at more than one location. The results also indicate some geographical variation within the diet of grey seals, but Atlantic herring (*Clupea harengus*) constitute a substantial part of the diet at several locations. However, no geographical variation is found within the Baltic ringed seal diet.

There seems to be a geographical variation between the diets of the harbour and the grey seal from the Southwestern Baltic Sea, nevertheless dab (*Limanda limanda*) and black goby (*Gobius niger*) are found as some of the primary food items in both seal species. Overall, there seems to be some geographical variation between the diet of the grey and the Baltic ringed seal in the Finnish Baltic Sea, Gulf of Finland and Gulf of Bothnia, even though they both prey on herring. However, the ringed seal preys substantially on three-spined sticklebacks (*Gasterosteus aculeatus*), which the grey seal rarely does. No geographical overlap occurs between the harbour seal and the Baltic ringed seal in the Danish Straits or the Baltic Sea, hence their diets have not been compared.

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# Introduction

Conflicts between commercial fisheries and seals are escalating in many countries including Denmark, Sweden and Finland (Hoffmann *et al.* 2015; Kauhala *et al.* 2011; Larsen *et al.* 2015; Lunneryd 2005). Many of these conflicts began after the seal populations started to recover from a long period of culling (Larsen *et al.* 2015). The recovery of seals began with the protection of them e.g. in Denmark the harbour seal (*Phoca vitulina)* became protected, first in 1967 where they were protected against hunting during their breeding season, and later on in 1977 where both the harbour seal and the grey seal (*Halichoerus grypus*) became completely protected (Jepsen *et al.* 2005). In Finland the grey seal became protected in 1982 and the Baltic ringed seal (*Pusa hispida)* in 1986 (Stenman & Pöyhönen 2005). Currently, the conflicts are increasing between the harbour seal and the fisheries in Limfjorden, Kattegat and in the Southwestern (SW) Baltic Sea (Hoffmann *et al.* 2015; Larsen *et al.* 2015). In addition, the Swedish coastal fisheries are also suffering big economic losses due to the conflicts with the seal populations (Lunneryd 2005). The complains from the fishermen comprise of; the seals destroying their gear, eating their catches, dispersing parasites which reduce the value of the fish flesh and the seals presence decreases the presence and availability of commercially important fish species (Heide-Jørgensen 1987; Larsen *et al.* 2015). It is however still unclear whether the seals have an effect on the fish stocks and if so, to which extent they affect the fish and fisheries. Hansen & Harding (2006) investigated the potential impact of harbour seals on the cod (*Gadus morhua*) population in the eastern North Sea and their analysis indicated a negligible impact on the cod fishery. Similar results is established in a study from the Scotian Shelf, Canada, by Mohn & Bowen (1996) who found that a grey seal population, even though it was increasing, was not the major factor of the collapse of the Atlantic cod stock. Additionally, the consumption of the herring (*Clupea harengus*) in the Bothnian Sea by grey seals is estimated by Gårdmark *et al.* (2012) to have a low impact on the abundance of the herring population, even though the grey seal population has increased fivefold. Lindegren *et al.* (2011) furthermore suggests that resource availability and interspecific competition is a more important factor, which affects the herring stock in the Bothnian Sea compared to fisheries, predation by marine mammals and predatory fish species. Hence, it is important to investigate the diet of harbour seals, grey seals and Baltic ringed seals, to further examine if there is a potential for conflict between the fishery and the seals, but also to better understand the seals ecological role in the marine ecosystem.

Three seal species, the harbour seal, the grey seal and the Baltic ringed seal, are associated with the greater Baltic Sea region, which includes the Danish Straits. However, Baltic ringed seal are typically associated to the inner parts of the Baltic Sea, e.g. Bothnian Bay, nevertheless they also inhabit the Gulf of Finland, the Archipelago Sea, the Gulf of Riga and the Estonian coastal waters (HELCOM 2009). However, the grey seals are present in dispersed groups throughout the Baltic Sea, nevertheless, they are generally concentrated in the Northern part of the Baltic Proper (HELCOM 2009). The harbour seals occur in the Southwestern part of the Baltic Sea and throughout the Danish Straits (Fig. 1) (HELCOM 2009).

Harbour seals are typically associated with coastal waters (Larsen *et al.* 2015) and are known as being generalists, polyphagous and opportunistic feeders (Andersen *et al.* 2004; Andersen *et al.*

2007; Härkönen 1987; Olsen & Bjørge 1995) though they might focus on certain key species (Härkönen 1987; Olsen & Bjørge 1995; Tollit & Thompson 1996). However, these key species can vary seasonally (Andersen *et al.* 2007; Härkönen 1987; Olsen & Bjørge 1995; Tollit & Thompson 1996) and geographically (Andersen *et al.* 2007; Härkönen 1987; Härkönen 1988b; Olsen & Bjørge 1995). Studies indicate that harbour seals prefer foraging at the seabed at depths of 30 meters or less, with none or scarce vegetation (Härkönen 1988a; Olsen & Bjørge 1995).
Similarly are the grey seals considered to be generalists and opportunistic feeders (Stenman & Pöyhönen 2005; Suuronen & Lehtonen 2012). However, Grellier & Hammond (2006) suggest that grey seal populations might be a collection of specialists or that a population contains both specialist and generalists. The grey seals are also associated with coastal waters (Hoffmann *et al.* 2015), but they are also known to forage at larger distances from the coast and the colonies compared to harbour seals (Dietz *et al.* 2003).
Baltic ringed seals are also found to be generalist (Sinisalo *et al.* 2008) and opportunistic (Stenman & Pöyhönen 2005) feeders.

The aim of this study is to investigate if there is a geographical variation within and between the harbour seal, grey seal and Baltic ringed seal diet in the Danish waters and the Baltic Sea. This will be examined by analysing data gathered from several published and unpublished studies (Appendix A). Then, the diet of the three different seal species will be compared from various areas within the greater Baltic Sea, to see if a geographical variation occurs. Only fish species will be analysed in the different seal diets, however also crustaceans and other invertebrates have been identified in several studies (Sinisalo 2007; Sinisalo *et al.* 2008; Söderberg 1975).

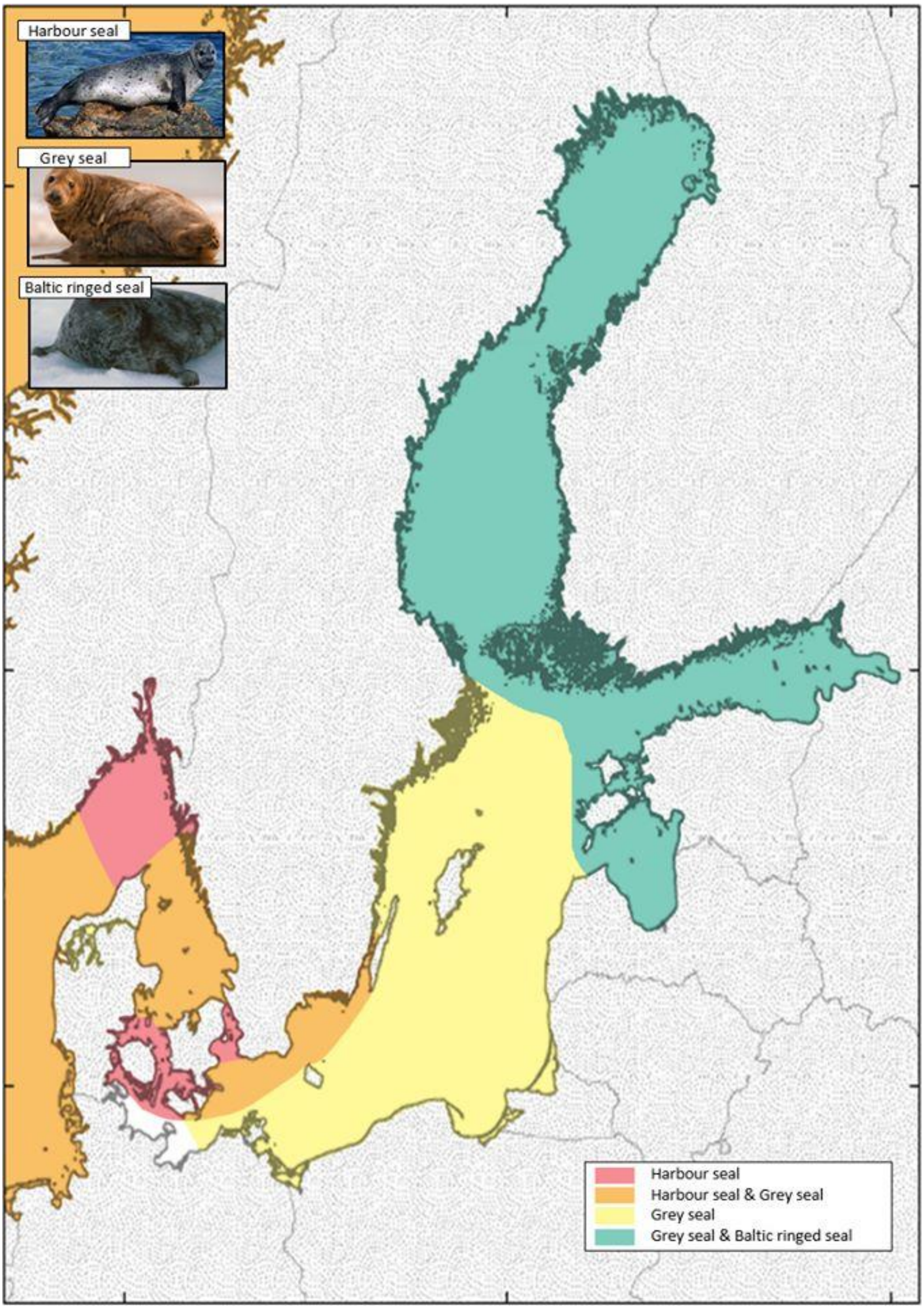


**Figure 1: Map of the greater Baltic Sea showing the distribution of the three seal species; harbour seal (*Phoca vitulina*), grey seal (*Halichoerus grypus*) and Baltic ringed seal (*Pusa* hispida), examined in this study as well as a picture of how each species look. Colour code on the map; Red: Where harbour seals is distributed; Orange: Where both harbour and grey seals are distributed; Yellow: Where grey seals are distributed; Green: where both grey seals and Baltic ringed seals are distributed. Harbour seal image by Mary Plaige (gettyimages.com): Common seal on seashore. Grey seal image by Craig Jones: Female grey seal on beach. Baltic ringed seal image by Doug Allan: Ringed seal profile.**

# Materials and methods

Data has been gathered from published and unpublished studies to investigate the geographic variations in the diet of seals in the Danish waters and the Baltic Sea (Table 1; Appendix A). These studies span over four decades, from 1975 to 2014, and the samples have been collected in Limfjorden, Skagerrak, Kattegat and within the Baltic Sea (Fig. 2).

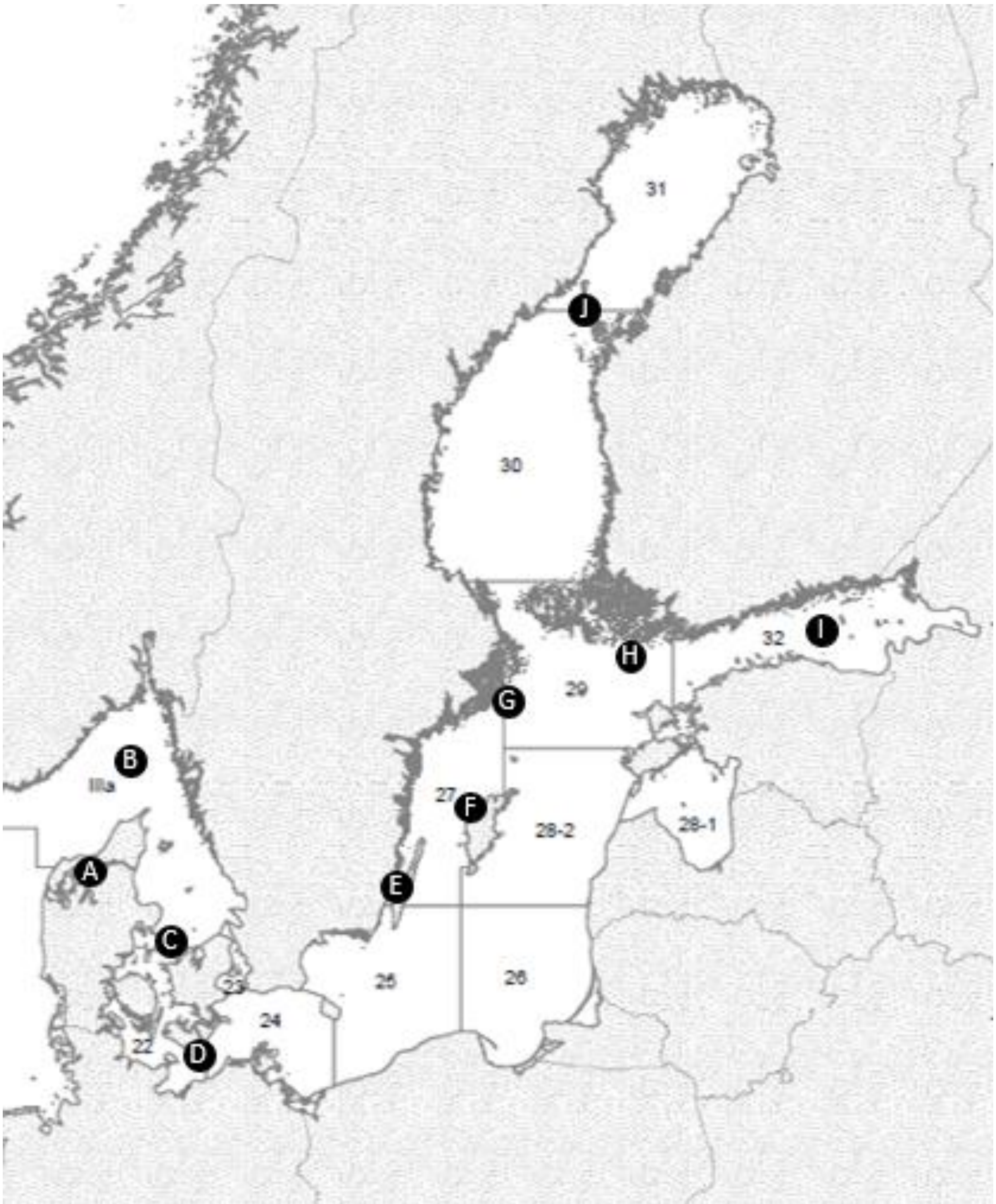


**Figure 2: An ICES (2015) map of the Danish waters and the Baltic Sea. The letters indicates different areas of the Danish waters and the Baltic Sea where seals and scats have been collected. A: Limfjorden; B: Skagerrak; C: Kattegat; D: Southwestern Baltic Sea; E: Kalmarsund; F: Gotland; G: Swedish Baltic Sea (incl. western Baltic Proper); H: Finnish Baltic Sea (incl. Archipelago Sea & eastern Baltic Proper); I: Gulf of Finland; J: Gulf of Bothnia. See table 1 for further information about which studies that collected which seal species and/or scats at the different locations or Appendix A for detailed information about the studies.**

The samples have been collected differently in the various studies, but it was either seal scats or whole seal individuals that have been collected (Table 1; Appendix A). The scats and digestive tracts were then examined, typically to find otoliths from fish and/or other hard parts. Afterwards the otoliths and hard parts were identified to family and species level if possible. The results in each individual study is presented in different ways e.g.; as the total count of otoliths found, as the estimated weight percentage, or just as a lists with an overview of which families or species they found in their samples. Therefore, to compare the data I constructed presence/absence tables and when possible I estimated the total number of otoliths recovered, if this was not already presented in the studies.

**Table 1: Shows the symbols used on the map (Fig. 2) and a reference to the studies which collected and investigated the samples within the different areas and which seal species the collected sample(s) was. The squares highlighted with grey indicates that the samples from that specific seal species was collected within that area. The squares that are blank, indicates that there were no samples of that seal species collected within that area. See Appendix A for information about the number of samples and sampling periods where the surveys were collected and conducted.**

| Symbols on the map | Location | Harbour seals (*Phoca vitulina)* | Grey seals (*Halichoerus grypus*) | Baltic ringed seals (*Pusa hispida*) | Reference(s) |
|---|---|---|---|---|---|
| **A** | **Limfjorden** | | | | [1] |
| **B** | **Skagerrak** | | | | [2] |
| **C** | **Kattegat** | | | | [3] |
| **D** | **Southwestern Baltic Sea** | | | | [4] |
| **E** | **Kalmarsund** | | | | [5] |
| **F** | **Gotland** | | | | [6] |
| **G** | **Swedish Baltic Sea*** | | | | [7] |
| **H** | **Finnish Baltic Sea**** | | | | [8] |
| **I** | **Gulf of Finland** | | | | [9] |
| **J** | **Gulf of Bothnia** | | | | [10] |

**[1] Andersen et al. (2007) and Friis et al. (1994). [2] Härkönen (1987) and Härkönen & Heide-Jørgensen (1991). [3] Härkönen (1988a) and Strömberg et al. (2013). [4] Andersen et al. (2007) and Jarnit (2014). [5] Söderberg (1975). [6] Asp (2011). [7] Strömberg et al. (2013), Söderberg (1975) and Lundström et al. (2007). [8] Stenman & Pöyhönen (2005) and Kauhala et al.(2011). [9] Stenman & Pöyhönen (2005) and Tormosov & Rezvov (1978). [10] Lagström (2007), Lundström et al. (2014), Sinisalo (2007), Sinisalo et al. (2008; 2006), Strömberg et al. (2013), Söderberg (1975) and Suuronen & Lehtonen (2012).**
***including north-western Baltic Proper**
**** including Archipelago Sea & North-eastern Baltic Proper**

The data from Asp (2011), Härkönen (1988a), Härkönen & Heide-Jørgensen (1991), Friis *et al.* (1994) and Jarnit (2014) was already given in the total number of otoliths found from each prey species, so here I did nothing to change the unit.
In Andersen *et al.* (2007), Lundström *et al.* (2007), Suuronen & Lehtonen (2012), Lagström (2007) and Söderberg (1975), they had divided the total number of otoliths, or the highest number of either left or right sided otoliths found with two, to get an estimate of the number of individuals eaten. Hence, I multiplied by two to get an estimate of the total number of otoliths found from each prey species.
Härkönen (1987) have the data as weight percentage and Tormosov & Rezvov (1978), Strömberg *et al.* (2013), Lundström *et al.* (2014) and Kauhala *et al.* (2011) have the data in frequency of

occurrence. Because there were no counts in these studies of how many otoliths were recovered, I have used a “p” to indicate that the species was present and found at least once.
Stenman & Pöyhönen (2005), Sinisalo (2007) and Sinisalo *et al.* (2008; 2006) only mention which fish species that were found in their investigation, but do not tell how many of each. Hence, the fish species that were mentioned in their studies, have been indicated with a “p” in my analysis to show that the species were present and found at least once.

In some of the studies (Lagström 2007; Sinisalo 2007; Sinisalo *et al.* 2008; Sinisalo *et al.* 2006; Söderberg 1975; Tormosov & Rezvov 1978) they found and included crustaceans and invertebrates in their results. However, in my study, only fish is being analysed and therefore the crustaceans and invertebrates have been excluded from the analysis, but please note that they were found in several studies. Furthermore, empty stomachs and intestines were also found, as well as some individuals whom had ingested small stones (Sinisalo 2007; Sinisalo *et al.* 2008; Sinisalo *et al.* 2006), but these have not been included in this study either. To compare which fish species that were eaten at the different geographic locations by each seal species, all the otoliths that were counted and those species indicated with a “p”, from all the studies were grouped together for each of the 10 locations (A-J). From this grouped data, three tables were constructed to show which fish species were present and absent within each of the seal species diets in the different areas. The grouped data was moreover used to investigate and compare the geographical variations between the diets of the three seal species. This was done by only using the locations where two of the seal species were found, and then making a table showing which fish species were present and absent in both seal species diets.
Furthermore, based on the numbers of otoliths from each prey species, excluding the fish species that were only indicated with a “p”, I calculated the frequency of occurrence of each fish species within each area for the different seal species.

In summary, the results are presented both in terms of presence/absence and in terms of the number of otoliths when such data was available. All data analyses were performed in Microsoft Excel 2013.

# Results

## Diet of the three seal species

### The harbour seal

A total of 52 fish species were recovered from the harbour seal samples within all the areas where these were collected (Appendix B).
In Limfjorden (A), Harbour seals prey on a minimum of 18 fish species (Table 2; Appendix B). They primarily feed on black goby (*Gobius niger*) (29.6%) and sand goby (*Pomatoschistus minutus*) (29.6%) and to a lesser extent on viviparous eelpout (*Zoarces viviparus*) (13.3%) and sprat (*Sprattus sprattus*) (10.8%) (Appendix E).
A minimum of 40 fish species were identified as prey items to the harbour seals in Skagerrak (B) (Table 2; Appendix B). This is the highest amount of prey species identified between all three seal species investigated, but also between all 10 locations where samples were collected. In Skagerrak, they typically feed on Norway pout (*Trisopterus esmarkii*) (23.6%) and unidentified sand lances (*Ammodytes sp.*) (19.1%), whereas whiting (*Merlangius merlangus*) (12.6%) and Atlantic cod (11.4%) are fed on to a lesser extent (Appendix E).

At least 21 fish species were identified from the harbour seal samples collected in Kattegat (C) (Table 2; Appendix B). In the Kattegat, one of the primary food sources is unidentified sand lances (39.1%) but also dab (*Limanda limanda*) (37.7%) are an important prey item at this location (Appendix E).

In the SW Baltic Sea (D) were 21 fish species found in the collected samples (Table 2; Appendix B). However, lesser sand eel (*Ammodytes tobianus*), black goby and Atlantic cod are the primary food items, consisting of 44.5%, 15.1%, 11.5% of the harbour seals diet, respectively (Appendix E).

Harbour seals are found to prey on a minimum of 5 fish species in Kalmarsund (E), this is the least prey species found at any location where harbour seal samples were collected (Table 2; Appendix B). However, only 48 otoliths were recovered in the samples collected in Kalmarsund. Out of these 48 otoliths, are 20 from European eel (*Anguilla anguilla*) (41.7%), 8 from Atlantic cod (16.7%), 8 from European flounder (*Platichthys flesus*) (16.7%) and another 8 from European whitefish (*Coregonus lavaretus*) (16.7%) (Appendix E).

### The grey seal

A total of 46 fish species were recovered from the grey seal samples within all the areas where these were collected (Appendix C).
In the SW Baltic Sea (D) have a minimum of 9 fish species been identified (Table 2; Appendix C). However, only 31 otoliths were recovered from the grey seal samples collected at the SW Baltic Sea. 12 (38.7%) of these are identified as black goby and 9 (29.0%) as round goby (*Neogobius melanostomus*) (Appendix F).

Also in the samples collected at Gotland (F) are a minimum of 9 fish species identified (Table 2; Appendix C). Nevertheless, in the samples from Gotland 530 otoliths were recovered and the

primary food items identified are Atlantic herring, sprat and Atlantic cod which consisted of 32.6%, 31.3% and 24.5% of the grey seal diet, respectively (Appendix F).
A minimum of 32 fish species are identified in the samples from the Swedish Baltic Sea (G) (Table 2; Appendix C). This is the highest amount of identified prey species found when comparing the 6 locations where grey seals have been sampled. Atlantic herring are the dominating food item found in the Swedish Baltic Sea with 6908 (70.4%) out of the 9808 otoliths recovered from this location, and are followed by the sprat (9.4%) (Appendix F).
Grey seals are found to prey on a minimum of 17 and 9 fish species in the Finnish Baltic Sea (H) and the Gulf of Finland (I), respectively (Table 2; Appendix C). However, none of the studies used in the grouped data for the Finnish Baltic Sea (Kauhala *et al.* 2011; Stenman & Pöyhönen 2005) and the Gulf of Finland (Tormosov & Rezvov 1978) informed, how many otoliths they recovered from the samples. Therefore, it is not possible to calculate the frequency of occurrence for each prey species identified from the samples within these two areas.
In the Gulf of Bothnia (J) a minimum of 17 fish species were identified (Table 2; Appendix C). 3716 otoliths were recovered in the samples of grey seal collected in the Gulf of Bothnia. 24.4% of the otoliths are herring and 36.8% are vendace (*Coregonus albula*). 9.8% are unidentified otoliths and an additional 7.9% of the otoliths are recognized to belong to the Coregonus family, but not further specified to species level (Appendix F).

#### The Baltic ringed seal

A total of 20 fish species were recovered from the Baltic ringed seal samples within all the areas where these were collected (Appendix D).
In the Finnish Baltic Sea (H) and the Gulf of Finland (I), the Baltic Ringed seals were found to prey on a minimum of 5 and 7 fish species, respectively (Table 2; Appendix D). However, there is no information presented about how many otoliths that have been recovered in the studies included in the grouped data of the Baltic ringed seals from these two areas (Stenman & Pöyhönen 2005; Tormosov & Rezvov 1978). Hence, it is not possible to calculate the frequency of occurrence of each prey species in the diet of ringed seals at these two locations.
A minimum of 20 fish species were identified as prey items for the Baltic ringed seal in the Gulf of Bothnia (Table 2; Appendix D). This is the highest number of fish species that the ringed seals has been found to feed on out of the three areas where the samples have been collected. Out of 4474 otoliths recovered from the Baltic ringed seal samples collected in the Gulf of Bothnia, 73.8% are identified as three-spined sticklebacks (*Gasterosteus aculeatus*) and 13.6% as Atlantic herring (Appendix G).

### Geographic variation in the diet between the three seal species

#### Comparison of the harbour and Baltic ringed seal

The habitats of the Baltic ringed seal and the harbour seal do not overlap geographically, hence their respective diets have not been compared (Fig. 1).

### Comparison of the harbour and grey seal in the Southwestern Baltic Sea

Samples from both harbour seals and grey seals have been collected from the SW Baltic Sea. Lesser sand eel (44.5% and 3.2%), black goby (15.1% and 38.7%), round goby (0.3% and 29.0%), sand goby (0.1% and 3.2%), dab (6.3% and 9.7%) and plaice (*Pleuronectes platessa*) (1.8% and 6.5%) are all found in the diet of both the harbour seal and the grey seal within this area, respectively (Fig. 3; Fig. 4; Appendix H). Hence, a minimum of 5 out of a total of 21 and 9 fish species are fed on by both the harbour seals and the grey seals, respectively (Table 2; Appendix H). However, as previously mentioned, only 31 otoliths were recovered from the grey seal samples collected at this location.

### Comparison of the grey and Baltic ringed seal

The grey seal and Baltic ringed seal samples that have been collected, overlap in three geographical areas; The Finnish Baltic Sea, the Gulf of Finland and the Gulf of Bothnia. However, the only results from the Finnish Baltic Sea and the Gulf of Finland are whether the fish species have been found or not.

#### *The Finnish Baltic Sea*

In the Finnish Baltic Sea, 5 fish species out of a total of 17 and 5 fish species were found in the diet of both grey seals and ringed seals, respectively. The 5 species are: Herring, three-spined sticklebacks, European whitefish, Atlantic salmon (*Salmo salar*) and brown trout (*Salmo trutta*) (Appendix H).

#### *The Gulf of Finland*

In the Gulf of Finland there are herring, sprat, river lamprey (*Lampetra fluviatilis*) and viviparous eelpout found. Hence, the same 4 species out of 9 and 7 fish species are found in the diet of both grey seals and ringed seals, respectively (Table 2; Appendix H).

#### *The Gulf of Bothnia*

In the Gulf of Bothnia, both the grey seal and ringed seal, feed on the same 13 fish species out of a total of 17 and 20 fish species found in their diet, respectively(Table 2; Appendix H). Unidentified sand lances (present and 1.6%), herring (24.4% and 13.6%), sprat (0.9% and present), three-spined sticklesback (0.1% and 73.8%), smelt (*Osmerus eperlanus*) (1.7% and 2.2%), perch (*Perca fluviatilis*) (1.0% and present), river lamprey (0.1% and present), vendace (36.8% and 2.6%), European whitefish (8.0% and 2.4%), Atlantic salmon (0.8% and 0.5%), brown trout ( 3.9% and 0.4%), unidentified salmonids (*Salmo sp.*) (0.5% and present) and viviparous eelpout (present and 0.3%) are all found in both grey seal and ringed seal diet, respectively (Fig. 4; Fig. 5; Appendix H).

**Table 2: A list of; how many fish species that was found, the estimated number of otoliths recovered and the total number of scats and digestive tracts that have been examined for each of the three seal species; harbour seal (*Phoca vitulina*), grey seal (*Halichoerus grypus*) and Baltic ringed seal (*Pusa hispida*) within each geographic area. Symbols on the map refers to figure 1. See Appendix A for further information about season and references to the original studies.**

| Symbols on the map: | Area: | Harbour seals: | | | Grey seals: | | | Baltic ringed seals: | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | The minimum number of fish species found: | Estimate of the total number of otoliths recovered: | The total number of scats and digestive tracts examined: | The minimum number of fish species found: | Estimate of the total number of otoliths recovered: | The total number of scats and digestive tracts examined: | The minimum number of fish species found: | Estimate of the total number of otoliths recovered: | The total number of scats and digestive tracts examined: |
| **A** | **Limfjorden** | 18 | 12245 | 138 scats | | | | | | |
| **B** | **Skagerrak** | 40 | 7408 | 346 scats | | | | | | |
| **C** | **Kattegat** | 21 | 2187 | 123 scats & 44 digestive tracts | | | | | | |
| **D** | **Southwestern Baltic Sea** | 21 | 1513 | 17 scats & 17 digestive tracts | 9 | 31 | 9 scats | | | |
| **E** | **Kalmarsund** | 5 | 48 | 7 digestive tracts | | | | | | |
| **F** | **Gotland** | | | | 9 | 530 | 41 scats | | | |
| **G** | **Swedish Baltic Sea** | | | | 32 | 9808 | 282 digestive tracts | | | |
| **H** | **Finnish Baltic Sea** | | | | 17 | ? | 697 digestive tracts | 5 | ? | 126 digestive tracts |
| **I** | **Gulf of Finland** | | | | 9 | ? | 43 digestive tracts | 7 | ? | 58 digestive tracts |
| **J** | **Gulf of Bothnia** | | | | 17 | 3716 | 174 digestive tracts | 20 | 4474 | 141 digestive tracts |

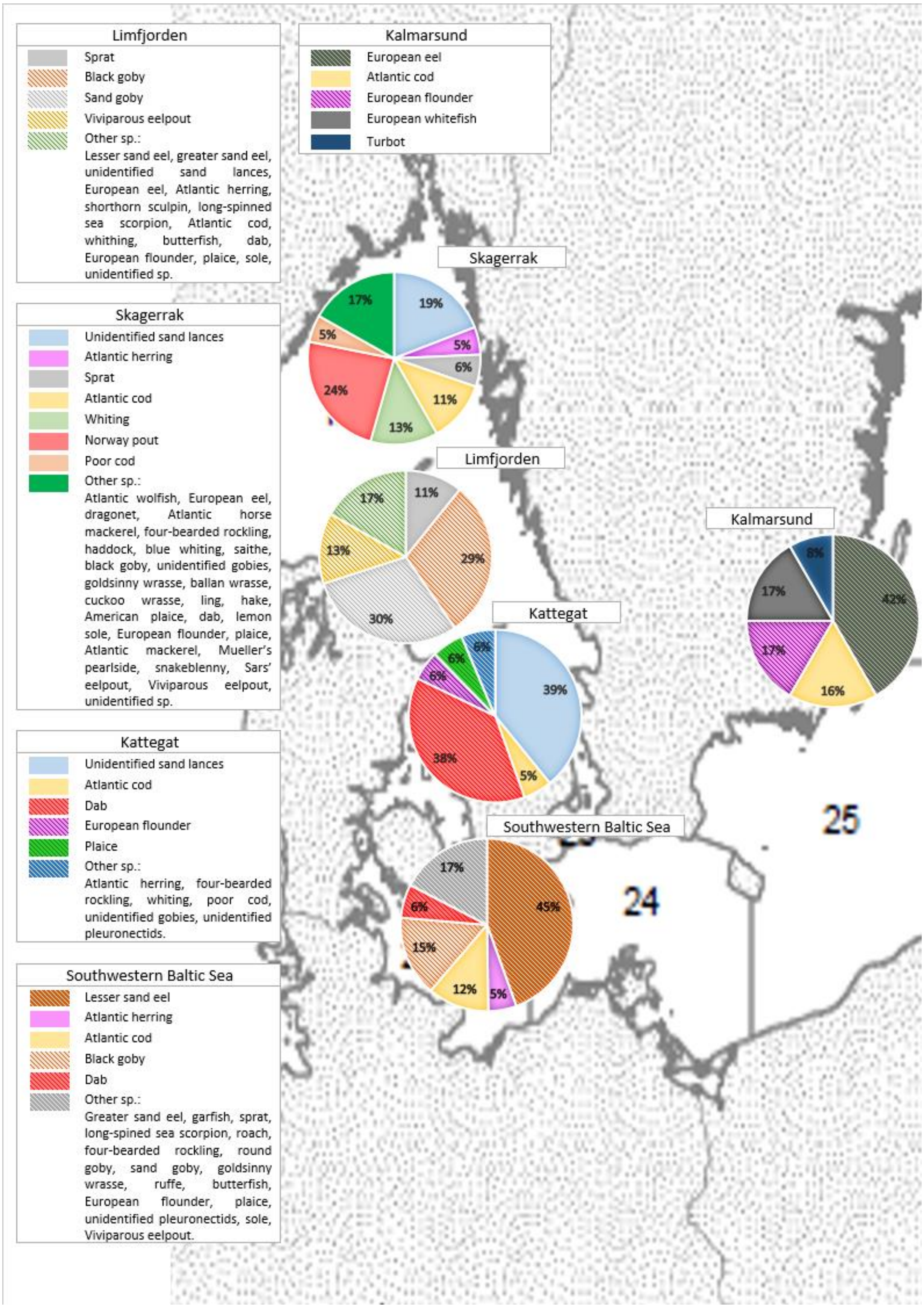


**Figure 3: Map of the most frequently occurring prey species (>5%) recovered in the samples of harbour seals (*Phoca vitulina*) from Limfjorden, Skagerrak, Kattegat, Southwestern Baltic Sea and Kalmarsund.**

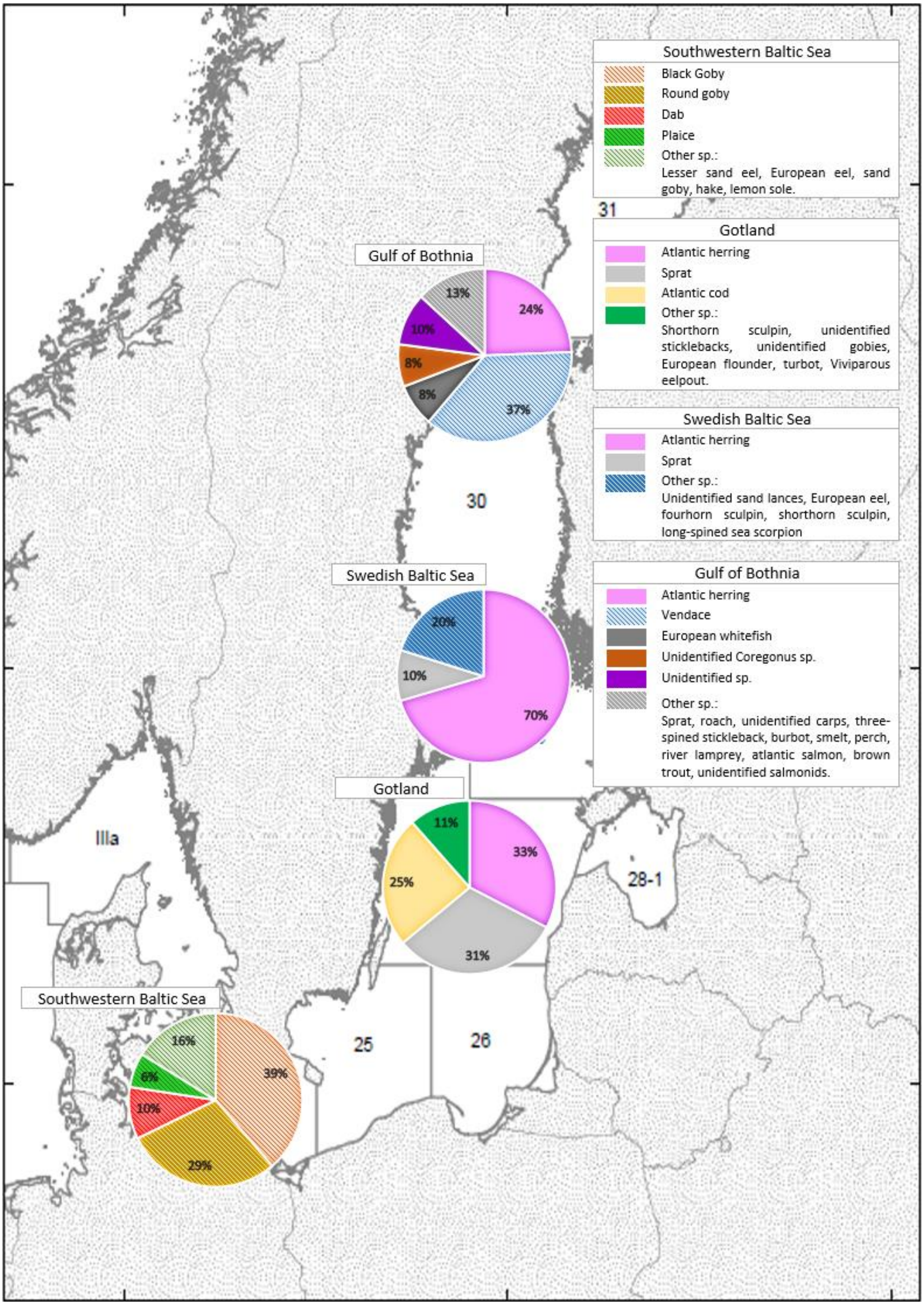


**Figure 4: Map of the most frequently occurring prey species (>5%) recovered in the samples of grey seals (*Halichoerus grypus*) from Southwestern Baltic Sea, Gotland, Swedish Baltic Sea and the Gulf of Bothnia.**

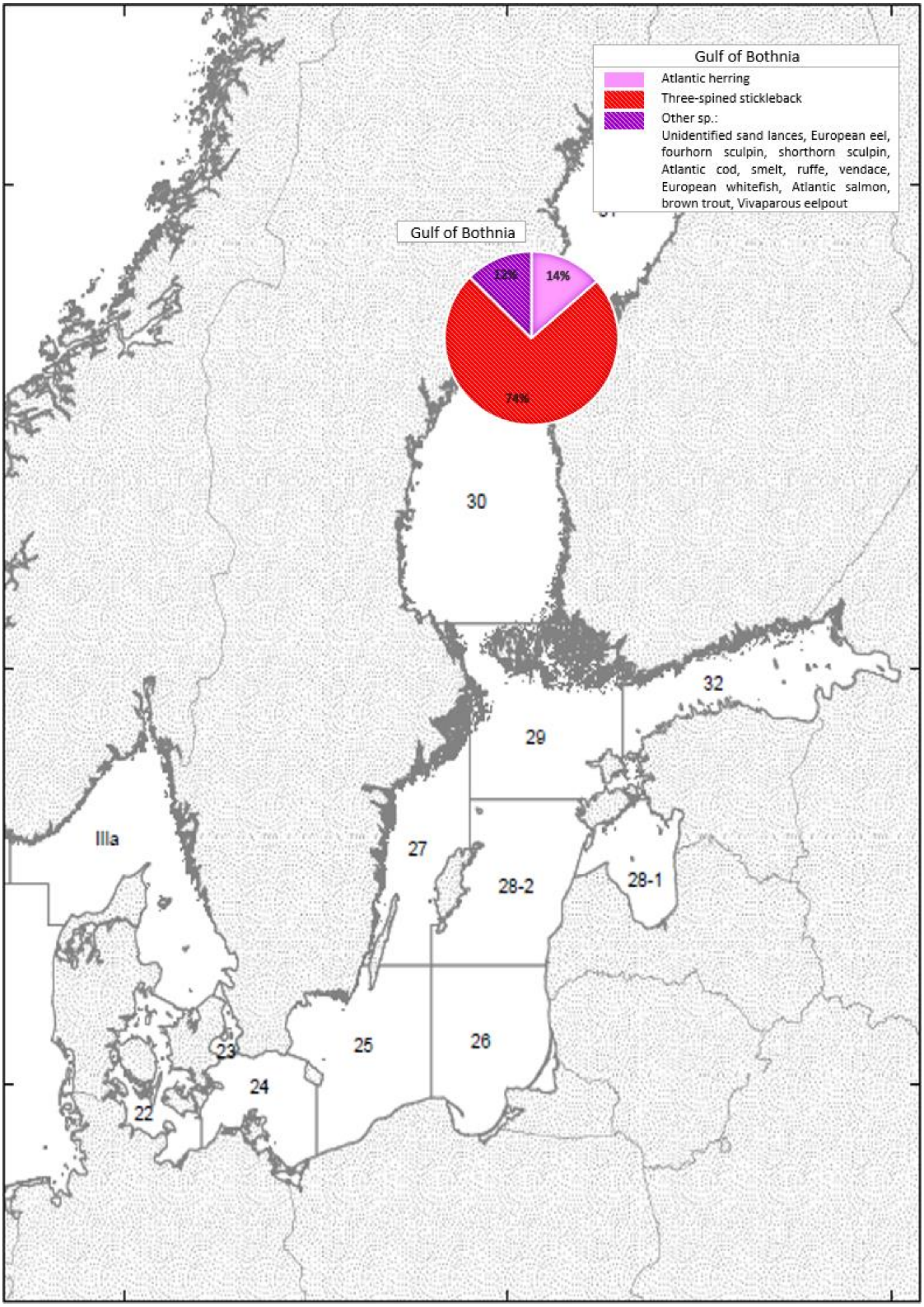


**Figure 5: Map of the most frequently occurring prey species (>5%) recovered in the samples of the Baltic ringed seal (*Pusa hispida*) from the Gulf of Bothnia.**

# Discussion

## Diet of the three seal species

### The Harbour seal

The results indicate a geographical variation within the diet of the harbour seal. Nevertheless, some fish species e.g. cod and sand lances occur in the diet from several areas. This can be due to the abundance and distribution of these fish species in these areas, e.g.: The cod is a marine species, thus it is most abundant in the saline areas such as the southernmost part of Kattegat, the southern and open Baltic, and Skagerrak (Bagge *et al.* 1994; HELCOM 2009; Hoffmann *et al.* 2015). This coincides with the results of where harbour seals are found to most frequently feed on cod.
The frequency of sand lances eaten by harbour seals increases from Skagerrak, through Kattegat and into the SW Baltic Sea. This increase in frequency could indicate that sand lances possibly increase in abundance, or that the diversity of fish species decreases, thus sand lances might become more important in the diet. Kattegat have a sandy seabed, thus have a smaller species diversity due to fewer niches (Härkönen 1988a). However, the increase in occurrence of sand lances in the diet can also be influenced by where the samples were collected. Three out of the four studies, which collected samples in Skagerrak, have been collected at Koster (Härkönen 1987; Härkönen & Heide-Jørgensen 1991; Härkönen 1988a). Koster is known to have a diverse rocky shore habitat with vegetation (Härkönen 1988a) which is not the typical environment for lesser sand eel or sand lances in general, which typically prefer sandy bottoms (O'Connell & Fives 1996) such as in Kattegat (Härkönen 1988a).
The lesser sand eel is known to be a coastal, demersal species (Härkönen 1988a) occurring down to 30 meters depth (Bonisławska *et al.* 2014; O'Connell & Fives 1996). Cods, whiting, flounder and black gobies are also benthic species (Härkönen 1988a; Höglund & Thomas 1992; Tomczak *et al.* 2013) which all occur frequently in the diet of the harbour seal at one or more locations. This supports the notion that the harbour seal prefer to forage on the seabed (Härkönen 1987; Härkönen & Heide-Jørgensen 1991; Härkönen 1988a). Nevertheless, pelagic fish species e.g. sprat (Tomczak *et al.* 2013), are also found as a frequent part of the diet at certain locations.
Another predator also known to feed on the seabed are the great cormorant (*Phalacrocorax carbo*). In addition, Andersen *et al.* (2007) established that both the great cormorants and harbour seals forage on some of the same fish species within the same areas. This leaves potential for interspecific competition between the harbour seal and great cormorant. Nevertheless, the great cormorants generally feed in shallow waters, whereas the harbour seal usually forage down to 30 meters (Härkönen 1988a). Thus, the competition might not be so direct between the two predators.

Several studies (Friis *et al.* 1994; Härkönen 1987; Härkönen & Heide-Jørgensen 1991) suggest that the geographic variation found in the diet of the harbour seal is simply a reflection of the species composition, prey availability and which fish species is most abundant in the given area. This indicates that the harbour seals are generalised and opportunistic predators. On the contrary, other studies have had indications of, that at some locations the locally abundant fish species have rarely been consumed by the seals (Härkönen & Heide-Jørgensen 1991; Härkönen 1987). This could indicate that the seals are specialising on certain prey items or that they are unable to catch these abundant species (Härkönen & Heide-Jørgensen, 1991). Lunneryd (2001) suggested that the individual seals might have a "personal" preference to certain prey items and this could be why we see a varying diet even within the same area.

#### The Grey seal

The results indicate that there are some geographical variations within the diet of grey seals. However, Atlantic herring are found as a substantial part of the grey seal diet in five out of the six sampled areas. Other studies had also concluded that herring had been the most important prey item in the Gulf of Finland, Finnish Baltic Sea and the northwestern (NW) Baltic Sea (Tormosov & Rezvov 1978; Kauhala *et al.* 2011; Stenman & Pöyhönen 2005). This could indicate that there are no geographical variations in the diet within the NW part of the Baltic Sea. Nevertheless, when considering the other frequently occurring prey items e.g. cod, sprat, vendace and gobies, hence there seems to be some geographic variation.

It can be speculated that the minor geographical variation found in the grey seal diet, is due to which species that are available in the different areas, which is also suggested in a previous study (Lundström *et al.* 2007). For instance, vendace are only found as a substantial part of the grey seal diet in the Gulf of Bothnia. This coincides with Ådjers *et al.* (2006) who found that vendace have been caught mainly in the northern most areas and preferred cold waters.
In addition, sprat have a more southerly distribution in the Baltic Sea (Kauhala *et al.* 2011) and cod are more abundant in areas with more salinity e.g. the southern and open Baltic (HELCOM 2009). The results of this study also indicate that both species occur more frequently in the diet from the samples that have been collected at southerly locations. Hence, it is probable that further analysis could support the idea that grey seal are generalists and opportunistic feeders that feed on what is easily accessible within the given area (Stenman & Pöyhönen 2005; Suuronen & Lehtonen 2012).

In the Gulf of Finland Tormosov & Rezvov (1978) concluded that cod consisted of 11% of the grey seal diet. Nevertheless, in the Gulf of Finland the salinity is only around 2.0 PSU or less (Bonisławska *et al.* 2014; HELCOM 2009) whereas the Baltic Proper have 8.0 PSU and the Bothnian Sea have 5.0 PSU (HELCOM, 2009). Hence, it seems unlikely that the cod have been found constituting 11% of the diet in the Gulf of Finland. However, grey seals are known to swim long distances and in general move around more throughout the year compared to e.g. the harbour seal (Dietz *et al.* 2003). This could possibly explain the occurrence of cod in the diet of grey seals in the Gulf of Finland. Nevertheless, it could also be that the species composition was different in 1978 where the study has been published.

The results from Kauhala *et al.* (2011) indicate a difference in prey preference between the genders of the grey seal: that males feed on more varied fish species than females. They discuss that this difference could be selectivity seen in the females, caused by them having a greater energy demand than the males. However, another possible explanation could be that the males actually take longer foraging trips than females, thus a larger diversity of prey species are found in their diet (Sinisalo *et al.* 2008; Kauhala *et al.* 2011).
The results from Lundström *et al.* (2007) indicate that age between the sampled individuals as well as area had a significant effect on the diet composition. Furthermore, it was discovered that the young grey seal individuals eat more non-commercial species, whereas the adults feed on more economically important fish species (Lundström *et al.* 2010). Thus, the age of the sampled

individuals could influence the variations that are seen in the diet of grey seals. In addition, Kauhala *et al.* (2011) discusses that seals younger than 1 year of age, due to inexperience include fish in their diet, which were rarely fed on by adults. This can be why we occasionally find only a few otoliths from certain fish species e.g. zander (*Sander lucioperca*) or lumpsucker (*Cyclopterus lumpus*).

Both herring and sprat are pelagic species (Härkönen 1988; Tomczak *et al.* 2013) and these constitute a substantial number of the prey items of the grey seal at least in the northern Baltic Proper, Gulf of Bothnia and Gulf of Finland (Kauhala *et al.* 2011; Stenman & Pöyhönen 2005; Tormosov & Rezvov 1978). Hence, the grey seals, at least in this area, might prefer to feed on pelagic species. Nevertheless, also benthic species e.g. cod, round goby and black goby (Härkönen 1988a; Höglund & Thomas 1992; Kvach & Winkler 2011) are primary food sources in the SW Baltic Sea as well as cod in the northern part, which makes a possible preference for either benthic or pelagic species inconclusive.

#### The Baltic ringed seal

It has only been possible to calculate at which frequencies the different fish species occurs in the Gulf of Bothnia. The result indicate that three-spined stickleback are the primary prey item followed by herring within the Gulf of Bothnia. In addition, Stenman & Pöyhönen (2005) concluded that the Baltic ringed seals primary food source was herring, but also that the ringed seal frequently fed on three-spined stickleback within the Finnish Baltic Sea. Furthermore, according to Tormosov & Rezvov (1978), also in the Gulf of Finland, the three-spined stickleback were, together with the herring, the most common food items for the ringed seal, with a frequency on 34% and 33%, respectively. Hence, there are no geographical variations in the primary prey items of the Baltic ringed seal within its distribution in the Baltic Sea. The studies differ however as to which of the two species is the most important.

According to Lundström *et al.* (2014) had the feeding patterns of the Baltic ringed seal seemed to change in the Bothnian Bay since the 1970's, with an increase in the consumption of herring, vendace and three-spined stickleback, and a decrease in invertebrates. However, according to my results, the vendace are of relatively minor importance in the Baltic ringed seal diet from the Gulf of Bothnia. However, Sinisalo *et al.* (2006) concludes that there was a variation in the feeding habits amongst individual ringed seals. This could possibly help to explain why such a difference in the importance of vendace in the diet are seen. Furthermore, Sinisalo (2007) discusses if the quality of the food influences feeding specialisation of individual seals or if the individual seals become imprinted to forage on specific prey items as young. However, the difference in the importance of vendace in the diet could potentially be due to when and where in the Gulf of Bothnia, as well as other places, the samples have been collected.

Three-spined sticklesbacks are typically adapted to areas with low salinity, which makes the Gulf of Bothnia and Finland a seemingly ideal habitat with a salinity around 2.0 PSU or less (Bonisławska *et al.* 2014; HELCOM 2009). Hence, the Baltic ringed seals seems to be opportunistic feeders that feed on the species that are available, which have also been suggested in a previous study (Sinisalo 2007). On the contrary, three-spined sticklebacks are rarely recovered from the samples of the grey seals in these areas, thus it could be speculated that the Baltic ringed seals have specialised to feed on the three-spined sticklebacks. Furthermore, three-spined stickleback and herring are both pelagic

species (Härkönen 1988a; Tomczak *et al.* 2013) which indicates that the Baltic ringed seals primarily feeds on pelagic fish species.
Studies have also discovered that Baltic ringed seals possibly feed on crustaceans and other invertebrates. Söderberg (1975) discovered that the ringed seal feeds on two crustacean species; *Mesidothea entomon* and *Mysis relicta* during April-May and besides these two months they were not found during the rest of the year. At this period the females are nursing, thus they might not leave their pups alone for too long to go foraging, and therefore could rely on nearby crustaceans to feed on (Sinisalo *et al.* 2006; Sinisalo *et al.* 2008). However, cod are also found to feed on *Mesidothea entomon* (Bagge *et al.* 1994), thus another explanation could be that prior to being eaten by the seal, the cod could have consumed a *Mesidothea entomon* and therefore, the hard parts from the crustacean are found in the seals digestive tracts or scats.

## Geographic variation between the three seal species diets

### Comparison of the harbour and Baltic ringed seal

None of the collected samples of the Baltic ringed or the harbour seal overlap geographically (Fig. 1). Therefore, the diet of the two seal species cannot be compared within each area.

### Comparison of the harbour and grey seal in the Southwestern Baltic Sea

The samples of the harbour and the grey seal only overlap in the SW Baltic Sea. There are primarily variations between the two seal species diets at this location. Out of the 5 fish species which are found in the diet of both grey seals and harbour seals, only two fish species, dab and black goby, are among the primary prey items to both. Hence, both prey items could be a potential for competition between the two seal species. However, dab seems to be only of minor importance to both seal species, when comparing the frequencies of otoliths recovered from the other primary prey items, e.g. lesser sand eel in the harbour seal diet or the round goby in the grey seal diet (Fig. 3; Fig. 4). However, only 31 otoliths have been recovered in the grey seal samples at this location. Hence, more samples would need to be collected of grey seals from the SW Baltic Sea to get a more conclusive result of their diet.

### Comparison of the grey and Baltic ringed seal

A geographical overlap is present between the grey seal and the Baltic ringed seal samples collected in: the Finnish Baltic Sea, the Gulf of Finland and the Gulf of Bothnia.

#### *Gulf of Bothnia*

The results indicate that there is geographical variation between grey and Baltic ringed seals in the Gulf of Bothnia. Even though both species frequently prey on the herring, the ringed seal consumes more three-spined stickleback. Conversely, the results indicate that the three-spined sticklebacks are insignificant in the grey seal diet. Furthermore, vendace are important in the diet of grey seals where it is of minor importance in the ringed seal diet. Nevertheless, competition could occur between the two seal species in relation to the herring (Fig. 4; Fig. 5).

#### *Gulf of Finland*

It seems that there is a relatively small difference in the diet of grey seals and Baltic ringed seals in the Gulf of Finland. According to Tormosov & Rezvov (1978), herring are very important for both species consisting of 33% and 34% in ringed seals and grey seals diet, respectively. Viviparous eelpout are also found to be of some importance in their study, constituting 6% in ringed seals diet and 10% in grey seals. However, they found that three-spined sticklebacks are the most important species to Baltic ringed seals constituting 34%. In addition, the grey seals also frequently feed on cod (11%) and lampreys (13%) (Tormosov & Rezvov 1978). This causes some differentiation between the two seal species diets in the Gulf of Finland.

#### *Finnish Baltic Sea*

It seems that a relatively small variation occurs between the Baltic ringed seals and the grey seals in the Finnish Baltic Sea. Herring are the most important prey item for both grey seals and ringed seals (Stenman & Pöyhönen 2005; Kauhala *et al.* 2011) which indicates a minor variation in the diet and a potential for competition over this species. However, Stenman & Pöyhönen's (2005) results also indicated that the ringed seals frequently fed on three-spined sticklebacks, however they do not mention if the grey seal fed on this species. In addition, Kauhala *et al.* (2011) notes that they found three-spined sticklebacks in the diet of grey seals but not to which extent. Hence, this suggests some variation in the diet between the grey and Baltic ringed seal within the Finnish Baltic Sea.

### Conflicts with the fisheries

According to the results, cod is one of the primary food sources for the harbour and grey seal. However, cod are also important for the fisheries, which causes conflicts between seals and the fisheries. Nevertheless, studies have discovered that seal predation have a lower impact on the cod population and recovery in the Baltic Sea and in the eastern North Sea, compared to the effects of harvest by the fisheries and the salinity (Hansen & Harding 2006; MacKenzie *et al.* 2011). However, in Øresund (Denmark), the decline of caught cod is so immense that Larsen *el al.* (2015) states that if it continues, then in a few years there will not be any cod fishing left in the southern part of Øresund.

Herring also constitutes a substantial amount of the diet of Baltic ringed seals and grey seals but to a lesser extent in the harbour seal diet. Furthermore, herring is one of the most important fish species for the commercial fisheries in the Baltic Sea, hence causes conflicts. Even though the consumption of herring seems vast, studies have shown that at least the grey seal predation on herring has a low impact on the abundance of herring and that other factors affect the herring stock more than seal predation (Gårdmark *et al.* 2012; Lindegren *et al.* 2011). Since the Baltic ringed seal are few in number compared to the grey seal population, it seems probable that they would have an insignificant impact on the herring stock.

For the harbour seal, eels are the most common prey item at Kalmarsund. This high amount of eel in the diet of the harbour seal at the Swedish coast could be due to the Swedish eel fisheries. The damage to fishing gear and catch losses have increased in the Swedish eel fishery and are primarily caused by the harbour seal (Königson *et al.* 2006). In a study by Königson *et al.* (2006) they found that it was only certain seal individuals in each area, who specialised in attacking the fishing gear. Specifically fyke nets were attacked primarily to feed on eels. Conversely, Lunneryd (2001) found that the seals feeding from the cages refused to eat the eels, which suggest that they had been attracted to other prey items. Nevertheless, it is interesting to consider that the seals foraging e.g. on eel fyke nets might have specialised to this type of foraging. Therefore, culling of random seal individuals within certain populations most likely will not reduce this conflict since probably not all seal individuals will be specialised foragers (Sinisalo *et al.* 2006). Thus, if culling is to take place it has to be of those individuals, which are seen foraging of the eel fyke nets. However, another way of reducing these conflicts could be to improve the fishing gear so that it is harder for the seal to break in and eat the eel or other catches (Sinisalo *et al.* 2006).

The results from Jounela *et al.* (2006) indicates that there is an extensive catch loss for the fishery, particularly in the southern Gulf of Bothnia of salmon due to seal attacks. However, I found that salmon was of insignificant importance in the diet of both grey seals and ringed seals in the Gulf of Bothnia. In addition, also Stenman & Pöyhönen (2005) discovered that none of their samples of both grey seals and ringed seals, which had drowned in salmon nets in the Finnish Baltic Sea, had consumed salmon. This indicates that the seals probably are not going for the catch when they become entangled in the nets. Nevertheless, a possible explanation as to why I did not find large amounts of salmon could be due to; the otoliths of salmon being fragile towards digestions (Tollit *et al.* 2007), the head of the salmon was not ingested because of their typically larger size (Pitcher 1980) or the timing and location of the sampling period. Suuronen & Lehtonen (2012) discovered that salmon were only recovered in digestive tracts of grey seals during June-July. This is possibly related to the salmons spawning migration, which takes place in late May, and peaks in late June (Suuronen & Lehtonen 2012). It is also worth noting, that Suuronen & Lehtonen (2012) suggested that the grey seals could be a specialised predator, since grey seals in their study chose salmon over herring, even though herring were more abundant.

The conflicts are also escalating in the Danish Straits. Currently, in Kattegat only a few professional fisheries are present, if any at all. In addition, many fishers have given up on fishing in Limfjorden due to the many conflicts with seals (Larsen *et al.* 2015). Another issue, which is starting to occur, is that some harbour seal individuals have started to enter the streams e.g. Skjern å and Storå, to forage primarily on salmon and trout (Larsen *et al.* 2015).

In the Baltic Sea a restricted culling of seal occurs in Sweden but also Finland, Estonia as well as in the North Sea in Scotland and Norway (Larsen *et al.* 2015). Nevertheless, in the Wadden Sea both grey and harbour seals are completely protected (Larsen *et al.* 2015). However, a culling of the seal population might not reduce the conflicts, because even if the seal predation is eliminated, this would not necessarily mean that the fisheries catches would increase. Since, the seals also predate on other fish species e.g. cod, and the cod predates on yet another fish species e.g. the herring, which the fishermen also exploits (Gårdmark *et al.* 2012; Söderberg 1975). Hence, the seal indirectly enhances the survival of e.g. herring, by feeding on the competitors and predators e.g. the cod (Hansen & Harding 2006; Heide-Jørgensen 1987; Tormosov & Rezvov 1978).

Perhaps hunting seals that approach the fishing gear, might be a possible way to reduce the seal attacks (Jounela *et al.* 2006), since these individuals might be specialised foragers to feed of the fishing gear. Another thing to take into consideration when discussing the culling of seals, is the potentially negative effect it could have on the ecotourism that the country and/or local community might have on the seals. Because, if humans starts to hunt seals, they would become more scared and shy of human presence, which could cause them to flee when we approach them. Besides culling, another possible solution could be to improve the gear that the fishermen use and make it more "seal-proof" and/or to reduce the by-catch. Königson *et al.* (2007) found that the damage frequency decreased with modified fyke nets that had smaller mesh sizes, yet not to a completely acceptable level.

However, Larsen et al. (2015) suggested that it is possible that the economic consequences that the seals have on the fishery business are not as big as the loud debate makes it seem. However, it is understandable that the attacks from seals must be irritating for the fishermen, nevertheless, the economic loss might only be minor compared to their total income. Of course in certain areas, the conflict is so significant that it leaves the fishermen with big economic losses e.g. Limfjorden and Østersøen (Larsen et al. 2015). However, the fisheries and humans might also affect the seals fitness and survivability negatively, especially the younger individuals, by inducing fluctuations in the availability of prey (Härkönen & Heide-Jørgensen 1991).

## Potential errors

When determining the diet by using recovered otoliths and/or hard parts from scats and digestive tracts, there is a potential for bias, which can influence the results and obscure them in relation to the actual prey species and amount eaten.

A benefit of using scats to investigate the diet is that you do not have to kill the animal as you do when investigating digestive tracts. However, when analysing diet from otoliths and hard parts found in scats or digestive tracts, you only get an idea of what the predator has eaten within a few hours or days before (Grellier & Hammond 2006; Prime 1979).

When the fish are eaten, the otoliths can erode partly or be completely digested when moving through the digestive tract of the seal (da Silva & Neilson 1985; Jobling & Breiby 1986; Prime 1979). It appears that larger otoliths have a better recovery rate than smaller otoliths (Grellier & Hammond 2006). Hence, the smaller the consumed fish was, the greater is the probability of the otolith to be completely digested and underestimated (Prime 1979; da Silva & Neilson 1985). Furthermore, when the otoliths erode they can become harder to identify to species level (da Silva & Neilson 1985).

Studies have concluded that there is a difference in the degree of digestion and erosion: between different fish species (Prime 1979; da Silva & Neilson 1985; Jobling & Breiby 1986), between different individuals within the same fish species (Jobling & Breiby 1986; Tollit et al. 2007), as well as between different seals species (Casper *et al.* 2006; Marcus *et al.* 1998). Furthermore, meal size, meal frequency, meal composition and the seals activity could further affect the degree of otoliths and other hard parts digestion and recovery (Marcus *et al.* 1998; Casper *et al.* 2006). It also happens that the seal does not eat the head of their prey but only the body, hence no otolith of this prey individual will be recovered (Brown & Mate 1983; Pitcher 1980).

Seals that die entangled in fishing gear or are shot close to fishing gear might have a distorted abundance of otoliths in the digestive tracts compared to their "natural" food intake and could negatively affect the results (Söderberg 1972). However, Lundström et al. (2007) found no difference in the composition of prey species when comparing seals collected from fishing gear and elsewhere. However, larger datasets are to be emphasized to try and get as close as possible to the accurate estimation of the seals diet.

To improve the results of diet composition based on the analysis of otoliths and other hard parts, the use of species-specific correction factors could be beneficial. However, in a study by Lundström et al. (2007) they found that correction factors barely changed their results. Hence, correction factors have not been applied in this study.

Seasonal variation have in previous studies been discovered to occur (Andersen *et al.* 2007; Härkönen 1987; Olsen & Bjørge 1995; Tollit & Thompson 1996). Hence the time of the year where the samples have been collected could potentially influence the composition of species recovered from scats and digestive tracts as well as their importance in the diet. For some of the areas e.g. the Gulf of Finland have grey seal samples only been collected during summer. Hence if the diet varies throughout the year, some of the fish species that are considered important during the summer might not be found important in other seasons of the year. Thus, it might not even be possible to group together and compare the data from the same areas that have been sampled in different seasons, since each season possibly should be considered apart from each other. In addition, comparing two seal species diets with each other within the same region could be flawed if the samples are not collected in the same season and possibly even at the same year due to fluctuations in the fish stocks from year to year.

## Future changes and conclusion

The results indicate a geographical variation within the diet of harbour seals, even though some fish species e.g. cod and sand lances occurred as primary prey items at more than one area. In addition, the results indicate some geographical variation within the diet of grey seals, but Atlantic herring is a substantial amount of the diet in several areas. No geographical variation was discovered within the Baltic ringed seal diet between the three sampled areas.

There seems to be a geographical variation between harbour seals and grey seals from the SW Baltic Sea, nevertheless dab and black goby are found as some of the primary food items in both species. Overall, it seems likely that there is some geographical variation between the diet of grey seals and Baltic ringed seals in the Finnish Baltic Sea, Gulf of Finland and Bothnia, even though they both prey on herring. Because, ringed seals prey substantially on three-spined sticklebacks, which the grey seal rarely does.

Furthermore, no geographical overlap occurs between the harbour seal and the Baltic ringed seal in the Danish Straits or the Baltic Sea, hence their diets have not been compared.

Conflicts are reported to occur between the seals and the commercial fisheries, however to possibly a lesser extent than it sounds. However, if the seals are to be culled, it would seem most beneficial to go for the seals found close to the fishing gear, since it seems that these individuals specialise in attacking the gear. Hence, a random culling of the population would probably not ease the conflicts. Otherwise, trying to make the fishing gear “seal-safe” could be beneficial and hopefully help ease the conflicts.

Because the data analysed in this study has been collected over almost 40 years (from 1975-2014) differences in food preference is expected to have changed throughout the years. Thus,

it is uncertain if the results of this study actually represents the seal diets today. Nevertheless, the results do give an overview of which species might be preferred in the various areas investigated. Besides using otoliths alone, multiple different methods could be combined when studying the diet of seals to get a more accurate picture of their diet. For example, the combined use of DNA analysis together with otoliths is a possible way to estimate diet composition which might reduce some of the biases from both methods alone (Tollit *et al.* 2009). Nevertheless, DNA analysis alone cannot determine the abundance of the various species eaten, only whether they are present or not (Bowen & Iverson 2013). However, studies are trying to successfully quantify the species composition by using DNA (Bowles *et al.* 2011; Deagle & Tollit 2007).
Other methods to include when investigating the diet of seals could be fatty acids analysis of blubber (Käkelä & Hyvärinen 1998; Lind *et al.* 2012), or parasite burdens together with stable isotope ratios (Sinisalo 2007). The methods that record parasites have pros and cons since parasites only occur in infected animals, so if the seal feeds off uninfected individuals you will not see it (Sinisalo 2007).

When we have a better picture of the food intake and species composition of seals diet, it will help us understand the impact that seals have on the fish stocks in the Baltic Sea and Danish Straits, as well as their role in the marine ecosystem. This will help us to take a decision on what management plans to follow (Gårdmark *et al.* 2012).
Future work could be to create an online database where data concerning seals diet within different areas are entered and available for everyone, of course with limited editing possibility for the general public so only published and/or acknowledge information is published in the database. Furthermore, adding information about the distribution and frequency of occurrence of the fish species within different areas could be a beneficial tool when understanding seals choice of prey. Yet another thing to add, could be the areas where fishermen usually catch which fish species and where conflicts occur with seals. All to gain a better understanding of the conflicts and the seals biology.

In the future, we might see a change in the diet of the seals as the Baltic Sea and Danish waters possibly will change due to global warming which can cause a change in the species composition. If the seals are generalists and opportunist, they should change their diets as the species composition changes. However, if they are primarily specialised feeders, they might be negatively affected by this possible shift in species composition, of course depending on which fish species that will be best adapted to the possible global changes ahead.


# Acknowledgements

A special thanks to Morten T. Olsen for his guidance and help. In addition, a big thanks to Karl Lundström for his help providing data from published and unpublished studies investigating seals diets from Sweden and Finland.

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# Appendix A

**Appendix A: An overview of the studies I have been collecting data from to reanalyse. Furthermore, Information about which seal species the various studies were investigating, where the seals was collected, when the seals was collected, how the seals was collected and what was collected and analysed.**

| Reference to study | Harbour seal (*Phoca vitulina*) | Grey seal (*Halichoerus grypus*) | Baltic ringed seal (Pusa hispida) | Geographic location where samples were collected | Season/time period & year when samples collected | How did they investigate the diet? And how was their data presented? |
|---|---|---|---|---|---|---|
| **Andersen *et al.* (2007)** | n=106 scats<br><br>n=13 scats + 17 digestive tracts | 0 | 0 | Nissum Bredning (western Limfjord) & Løgstør Bredning (inner Limfjord)<br><br>Rødsand reserve/area(south of Falster island, south-western Baltic) | During spring, summer & autumn of 1997 and spring 1998<br><br>Scats from Rødsand were collected during March to November of 2001-2005 | Otoliths found in scats & digestive tracts. Sorted otoliths into left- and right-sided, and estimated the number of fish eaten.<br>Diet was shown as the estimated number of fish eaten. |
| **Asp (2011)** | 0 | n=41 scats | 0 | Salvorev (N 58º 1' E 19º 21'), Rute Missloper (N 57º 46' E 19º 5'), Raude Hunden (N 56º 58' E 18º 21') & Näsrevet (N 57º 3' E 18º 9'), at Gotland. | Collected seal scats in year 2010, from 9th-11th May, 19th-23th May, 14th-18th June, in the end of August, September-October, and in the beginning of November. As well as in the beginning and mid-January 2011. | Student project.<br>Seal scats were collected and investigated for hard parts.<br>A DNA analysis was also performed to complement the prey species diversity.<br>I have used data from table 3, which only included the total number of otoliths found. |
| **Friis *et al.* (1994)** | n=30 scats<br><br>n=2 scats | 0 | 0 | Ejerslev Røn in Limfjorden<br><br>Livø Tap in Limfjorden | 12th, 14th & 17th October, 1990. | Seal feces were collected. Otoliths were sorted and identified.<br>Diet was presented as number of otoliths recovered. |

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|---|---|---|---|---|---|---|
| **Härkönen (1987)** | n=314 scats<br><br>n=63 scats | 0 | 0 | South of Koster Island in Skagerrak<br><br>Anholt island in central Kattegat | Almost every month from 1977-1979.<br><br>July-September, 1980. | Feces were collected and otoliths were extracted and identified to species level.<br>8572 otoliths were found.<br>Diet was presented as weight percentage. |
| **Härkönen (1988)** | n=32 scats<br><br>n=60 scats | 0 | 0 | Koster<br><br>Kattegat (Anholt and Møllegrunden/Svane-grunden) | During June, 1980.<br><br>From May-September. | Scats were collected and otoliths were extracted and identified.<br>Diet was presented as total number of otoliths found for each prey species. |
| **Härkönen & Heide-Jørgensen (1991)** | n=? | 0 | 0 | Koster archipelago in Skagerrak | July-December, 1989. | Scats were collected and otoliths were identified to species level.<br>They do not write how many scats they collected.<br>Diet was given as total number of otoliths found for each prey species. |
| **Kauhala *et al.* (2011)** | 0 | n=136 digestive tracts | 0 | The Gulf of Finland, Southwest Archipelago, Bothnian Sea, Bothnian Bay & Kvarken. | 2001-2007. | In Finnish but with an English summary and figure description.<br>They used the stomachs and intestines to investigate the diet of grey seals. Prey items was mainly identified by the otoliths but also other hard parts were used.<br>Diet presented in frequency of occurrence. |
| **Lagström (2007)** | 0 | n=14 digestive tracts | 0 | 8 collected at Sundsvalls Bay & 6 collected in a area around Hårte in the Bothnian Sea. | Summer, 2007. | A student project.<br>Grey seals caught in seal traps/modified salmon traps and the content of hard parts (otoliths, scales and vertebrates) from the digestive tracts were identified.<br>Diet shown in a calculated number of prey individuals. |

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|---|---|---|---|---|---|---|
| **Lundström *et al.* (2007)** | 0 | n=138 digestive tracts | 0 | Gulf of Bothnia, Baltic Proper & a few with unknown origins. | Most of the individuals were collected from the last three quarters of the year, with a peak in May, from 2001-2004. | Bycaught and hunted seals. Otoliths and other hard parts were identified.<br>Diet was presented as estimated number of prey individuals eaten. |
| **Lundström *et al.* (2014)** | 0 | 0 | n=43 digestive tracts | Northwestern Bothnian Bay | 2007-2009, mainly from 2008. | Hunted seals.<br>Diet shown as frequency of occurrence and biomass index, which are based on otoliths and other hard parts recovered.<br>Ongoing investigation. |
| **Sinisalo *et al.* (2006; 2007; 2008)** | 0 | 0 | n=9 | Hailuoto Island in the northern part of the Gulf of Bothnia. | | Diet was identified by combining parasitological studies of the intestinal helminths, with analysis of the content of the alimentary tract and with stable isotope ratio analyses of seal tissue.<br>Diet are presented by listing which species that are present. |
| **Stenman & Pöyhönen (2005)** | 0 | n=561 digestive tracts | n=126 digestive tracts | Gulf of Finland, Archipelago Sea, Gulf of Bothnia. | 1986-2004 | Analysis of the content in digestive tracts, mainly based on identifying otoliths to species level.<br>Almost no details about the diet.<br>Before 2000, mainly bycaught young-of-the year individuals. |
| **Strömberg *et al.* (2013)** | n=44 | n=97 digestive tracts | 0 | 81 grey seals from the Gulf of Bothnia and 61 from the Baltic proper.<br><br>36 harbour seals from Kattegat and 8 harbour seals from Skagerrak. | 2010 | Digestive tracts were emptied and examined to find hard parts, which were identified to species level.<br>Diet presented as frequency of occurrence and weight proportion. |
| **Suuronen & Lehtonen (2012)** | 0 | n=63 digestive tracts | n=37 digestive tracts | Northern part of the Bothnian Bay | From mid-May to late November, 2008 & 2009. | Seals were collected by shooting them.<br>Prey species were determined by identifying fish otoliths as well as |

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| | | | | | | other hard parts found in the digestive tracts.<br>Diet was estimated as number of individuals, by dividing the number of otoliths recovered. |
| **Söderberg (1975)** | n=7 digestive tracts | n=144 digestive tracts | n=52 digestive tracts | Harbour seals were collected in the Swedish Baltic sea.<br><br>Grey seals were mainly collected in the Baltic Proper.<br><br>Ringed seals were collected in the Gulf of Bothnia. | March 1968 to June 1971. | They examined digestive tracts to find otoliths, which were used to determine prey species.<br>They have calculated the number of individual prey species found to estimate the diet. |
| **Tormosov & Rezvov (1978)** | 0 | n=43 digestive tracts | n=58 digestive tracts | The Gulf of Finland | Grey seals data were collected from August-September.<br><br>Ringed seals data were collected from September-October. | Stomach contents and intestines were analysed and prey species was identified with otoliths and bone remains.<br>Diet was presented as frequency of occurrence. |
| **Jarnit (2014)** | n=4 scats | n=9 scats | 0 | Rødsand | 2014 | Unpublished student project.<br>Diet was presented as the number of otoliths recovered. |

# Appendix B

**Appendix B: Harbour seals (*Phoca vitulina*) geographic variations in diet shown as presence/absence of each fish species. The squares highlighted with grey indicate that the fish species have been found at least once in the samples from that location. If the squares are blank, this indicates that the fish species have not been found in any samples from that site. "Areas on the map" refers to fig. 1. Where; A: Limfjorden; B: Skagerrak; C: Kattegat; D: Southwestern Baltic Sea; E: Kalmarsund.**

| **Fish species:** | | **Areas on the map:** | **A** | **B** | **C** | **D** | **E** |
|---|---|---|---|---|---|---|---|
| **Family** | **Scientific name:** | **Common name:** | **Presence /absence** | **Presence /absence** | **Presence /absence** | **Presence /absence** | **Presence /absence** |
| Ammodytidae | *Ammodytes tobianus* | Lesser sand eel | | | | | |
| | *Hyperoplus lanceolatus* | Greater sand eel | | | | | |
| | *Ammodytes sp.* | Unidentified sand lances | | | | | |
| Anarhichadidae | *Anarhichas lupus* | Atlantic wolffish | | | | | |
| Anguillidae | *Anguilla anguilla* | European eel | | | | | |
| Argentinidae | *Argentina silus* | Greater argentine | | | | | |
| Belonidae | *Belone belone* | Garfish | | | | | |
| Callionymidae | *Callionymus lyra* | Dragonet | | | | | |
| Carangidae | *Trachurus trachurus* | Atlantic horse mackerel | | | | | |
| Clupeidae | *Clupea harengus* | Atlantic herring | | | | | |
| | *Sprattus sprattus* | Sprat | | | | | |
| Cottidae | *Myoxocephalus scorpius* | Shorthorn sculpin | | | | | |
| | *Taurulus bubalis* | Long-spined sea scorpion | | | | | |
| Cyprinidae | *Rutilus rutilus* | Roach | | | | | |
| Gadidae | *Enchelyopus cimbrius* | Four-bearded rockling | | | | | |
| | *Gadus morhua* | Atlantic cod | | | | | |
| | *Melanogrammus aeglefinus* | Haddock | | | | | |
| | *Merlangius merlangus* | Whiting | | | | | |
| | *Micromesistius poutassou* | Blue whiting | | | | | |
| | *Pollachius pollachius* | Pollack | | | | | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | *Pollachius virens* | Saithe | | | | | |
| | *Trisopterus esmarkii* | Norway pout | | | | | |
| | *Trisopterus minutus* | Poor cod | | | | | |
| | *Gadids sp.* | Unidentified gadids | | | | | |
| Gobiidae | *Gobius niger* | Black goby | | | | | |
| | *Neogobius melanostomus* | Round goby | | | | | |
| | *Pomatoschistus minutus* | Sand goby | | | | | |
| | Gobiids sp. | Unidentified gobies | | | | | |
| Labridae | *Ctenolabrus rupestris* | Goldsinny wrasse | | | | | |
| | *Labrus bergylta* | Ballan wrasse | | | | | |
| | *Labrus mixtus* | Cuckoo wrasse | | | | | |
| | *Labrids sp.* | Unidentified wrasses | | | | | |
| Lotidae | *Molva molva* | Ling | | | | | |
| Merlucciidae | *Merluccius merluccius* | Hake | | | | | |
| Percidae | *Gymnocephalus cernua* | Ruffe | | | | | |
| Pholidae | *Pholis gunnellus* | Butterfish | | | | | |
| Pleuronectidae | *Glyptocephalus cynoglossus* | Witch | | | | | |
| | *Hippoglossoides platessoides* | American plaice | | | | | |
| | *Limanda limanda* | Dab | | | | | |
| | *Microstomus kitt* | Lemon sole | | | | | |
| | *Platichthys flesus* | European flounder | | | | | |
| | *Pleuronectes platessa* | Plaice | | | | | |
| | Pleuronectids sp. | Unidentified pleuronectids | | | | | |
| Salmonidae | *Coregonus lavaretus* | European whitefish | | | | | |
| | | Unidentified salmo sp. | | | | | |
| Scombridae | *Scomber scombrus* | Atlantic mackerel | | | | | |
| Scophthalmidae | Scophthalmus maximus | Turbot | | | | | |

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|---|---|---|---|---|---|---|---|
| Solenidae | *Solea solea* | Sole | | | | | |
| Sternoptychidae | *Maurolicus muelleri* | Mueller's pearlside | | | | | |
| Stichaeidae | *Lumpenus lampretaeformis* | Snakeblenny | | | | | |
| Zoarcidae | *Lycenchelys sarsi* | Sars' eelpout | | | | | |
| | *Zoarces viviparus* | Viviparous eelpout | | | | | |
| | | **Total species found:** | 18 | 40 | 21 | 21 | 5 |

# Appendix C

**Appendix C: Grey seals (*Halichoerus grypus*) geographic variations in diet shown as presence/absence of each fish species. The squares highlighted with grey indicate that the fish species have been found at least once in the samples from that location. If the squares are blank, this indicates that the fish species have not been found in any samples from that site. "Areas on the map" refers to fig. 1. Where; D: Southwestern Baltic Sea; F: Gotland; G: Swedish Baltic Sea; H: Finnish Baltic Sea; I: Gulf of Finland; J: Gulf of Bothnia.**

| **Fish species:** | | **Areas on the map:** | **D** | **F** | **G** | **H** | **I** | **J** |
|---|---|---|---|---|---|---|---|---|
| **Family:** | **Scientific name:** | **Common name:** | **Presence /absence** | **Presence /absence** | **Presence /absence** | **Presence /absence** | **Presence /absence** | **Presence /absence** |
| Ammodytidae | *Ammodytes tobianus* | Lesser sand eel | | | | | | |
| | *Hyperoplus lanceolatus* | Greater sand eel | | | | | | |
| | *Ammodytes sp.* | Unidentified sand lances | | | | | | |
| Anguillidae | *Anguilla anguilla* | European eel | | | | | | |
| Clupeidae | *Clupea harengus* | Atlantic herring | | | | | | |
| | *Sprattus Sprattus* | Sprat | | | | | | |
| Cottidae | *Myoxocephalus quadricornis* | Fourhorn sculpin | | | | | | |
| | *Myoxocephalus scorpius* | Shorthorn sculpin | | | | | | |
| | *Taurulus bubalis* | Long-spined sea scorpion | | | | | | |
| | *Cottids sp* | Unidentified sculpins | | | | | | |
| Cyclopteridae | *Cyclopterus lumpus* | Lumpsucker | | | | | | |
| Cyprinidae | *Blicca bjoerkna* | White bream | | | | | | |
| | *Rutilus rutilus* | Roach | | | | | | |
| | *Cyprinids sp.* | Unidentified carps | | | | | | |
| Esocidae | *Esox lucius* | Northern pike | | | | | | |
| Gadidae | *Gadus morhua* | Atlantic cod | | | | | | |
| | *Merlangius merlangus* | Whiting | | | | | | |
| Gasterosteidae | *Gasterosteus aculeatus* | Three-spined stickleback | | | | | | |
| | *Gasterosteides sp.* | Unidentified sticklebacks | | | | | | |
| Gobiidae | *Gobius niger* | Black goby | | | | | | |
| | *Gobiusculus flavescens* | Two-spotted goby | | | | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | *Neogobius melanostomus* | Round goby | | | | | | |
| | *Pomatoschistus minutus* | Sand goby | | | | | | |
| | Gobiids sp. | Unidentified gobies | | | | | | |
| Lotidae | *Enchelyopus cimbrius* | Fourbeard rockling | | | | | | |
| | *Lota lota* | Burbot | | | | | | |
| Merlucciidae | *Merluccius merluccius* | Hake | | | | | | |
| Osmeridae | *Osmerus eperlanus* | Smelt | | | | | | |
| Percidae | *Gymnocephalus cernua* | Ruffe | | | | | | |
| | *Perca fluviatilis* | Perch | | | | | | |
| | *Sander lucioperca* | Zander | | | | | | |
| | *Percids sp.* | Unidentified percids | | | | | | |
| Petromyzontidae | *Lampetra fluviatilis* | River lamprey | | | | | | |
| Pleuronectidae | *Limanda limanda* | Dab | | | | | | |
| | *Microstomus kitt* | Lemon sole | | | | | | |
| | *Platichthys flesus* | European flounder | | | | | | |
| | *Pleuronectes platessa* | Plaice | | | | | | |
| | Pleuronectids sp. | Unidentified pleuronectids | | | | | | |
| Salmonidae | *Coregonus albula* | Vendace | | | | | | |
| | *Coregonus lavaretus* | European whitefish | | | | | | |
| | *Salmo salar* | Atlantic salmon | | | | | | |
| | *Salmo trutta* | Brown trout | | | | | | |
| | *Salmo sp.* | Unidentified salmonids | | | | | | |
| | *Coregonus sp.* | Unidentified *Coregonus sp.* | | | | | | |
| Scophthalmidae | Scophthalmus maximus | Turbot | | | | | | |
| Zoarcidae | *Zoarces viviparus* | Viviparous eelpout | | | | | | |
| | | **Total species found:** | **9** | **9** | **32** | **17** | **9** | **17** |

# Appendix D

**Appendix D: Baltic ringed seals (*Pusa hispida*) geographic variations in diet shown as presence/absence of each fish species. The squares highlighted with grey indicate that the fish species have been found at least once in the samples from that location. If the squares are blank, this indicates that the fish species have not been found in any samples from that site. "Areas on the map" refers to fig. 1. Where; H: Finnish Baltic Sea; I: Gulf of Finland; J: Gulf of Bothnia.**

| **Fish species:** | | **Areas on the map:** | **H** | **I** | **J** |
|---|---|---|---|---|---|
| **Family:** | **Scientific name:** | **Common name:** | **Presence /absence** | **Presence /absence** | **Presence /absence** |
| Ammodytidae | *Ammodytes tobianus* | Lesser sand eel | | | |
| | *Ammodytes sp.* | Unidentified sand lances | | | |
| Anguillidae | *Anguilla anguilla* | European eel | | | |
| Clupeidae | *Clupea harengus* | Atlantic herring | | | |
| | *Sprattus Sprattus* | Sprat | | | |
| Cottidae | *Myoxocephalus quadricornis* | Fourhorn sculpin | | | |
| | *Myoxocephalus scorpius* | Shorthorn sculpin | | | |
| Gadidae | *Gadus morhua* | Atlantic cod | | | |
| Gasterosteidae | *Gasterosteus aculeatus* | Three-spined stickleback | | | |
| Gobiidae | *Pomatoschistus minutus* | Sand goby | | | |
| Osmeridae | *Osmerus eperlanus* | Smelt | | | |
| Percidae | *Gymnocephalus cernua* | Ruffe | | | |
| | *Perca fluviatilis* | Perch | | | |
| Petromyzontidae | *Lampetra fluviatilis* | River lamprey | | | |
| Salmonidae | *Coregonus albula* | Vendace | | | |
| | *Coregonus lavaretus* | European whitefish | | | |
| | *Salmo salar* | Atlantic salmon | | | |
| | *Salmo trutta* | Brown trout | | | |
| | *Salmo sp.* | Unidentified salmonids | | | |
| Zoarcidae | *Zoarces viviparus* | Viviparous eelpout | | | |
| | | **Total species found:** | 5 | 7 | 20 |

# Appendix E

**Appendix E: Geographic variations in the harbour seals (*Phoca vitulina*) diet shown as the total count of otoliths recovered and as a percentage of each fish species frequency of occurrence out of the total otolith count within each geographic area. Fish species only indicated with a "p" for presence in the grouped data have been removed from this part of the analysis because frequency of occurrence cannot be calculated. "Areas on the map" refers to fig. 1. Where; A: Limfjorden; B: Skagerrak; C: Kattegat; D: Southwestern Baltic Sea; E: Kalmarsund.**

| **Fish species:** | | **Areas on the map:** | **A** | | **B** | | **C** | | **D** | | **E** | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Family:** | **Scientific name:** | **Common name:** | **Total number of otoliths found** | **%** | **Total number of otoliths found** | **%** | **Total number of otoliths found** | **%** | **Total number of otoliths found** | **%** | **Total number of otoliths found** | **%** |
| Ammodytidae | *Ammodytes tobianus* | Lesser sand eel | 412 | 3.4 | | | | | 673 | 44.5 | | |
| | *Hyperoplus lanceolatus* | Greater sand eel | 350 | 2.9 | | | | | 4 | 0.3 | | |
| | *Ammodytes sp.* | Unidentified sand lances | 5 | <0.1 | 1416 | 19.1 | 856 | 39.1 | | | | |
| Anarhichadidae | *Anarhichas lupus* | Atlantic wolffish | | | 7 | 0.1 | | | | | | |
| Anguillidae | *Anguilla anguilla* | European eel | 43 | 0.4 | 1 | <0.1 | | | | | 20 | 41.7 |
| Belonidae | *Belone belone* | Garfish | | | | | | | 14 | 0.9 | | |
| Callionymidae | *Callionymus lyra* | Dragonet | | | 11 | 0.1 | | | | | | |
| Carangidae | *Trachurus trachurus* | Atlantic horse mackerel | | | 3 | <0.1 | | | | | | |
| Clupeidae | *Clupea harengus* | Atlantic herring | 424 | 3.5 | 381 | 5.1 | 3 | 0.1 | 80 | 5.3 | | |
| | *Sprattus sprattus* | Sprat | 1318 | 10.8 | 446 | 6.0 | | | 30 | 2.0 | | |
| Cottidae | *Myoxocephalus scorpius* | Shorthorn sculpin | 94 | 0.8 | | | | | | | | |
| | *Taurulus bubalis* | Long-spined sea scorpion | 12 | 0.1 | | | | | 4 | 0.3 | | |
| Cyprinidae | *Rutilus rutilus* | Roach | | | | | | | 2 | 0.1 | | |
| Gadidae | *Enchelyopus cimbrius* | Four-bearded rockling | | | 66 | 0.9 | 50 | 2.3 | 6 | 0.4 | | |
| | *Gadus morhua* | Atlantic cod | 2 | <0.1 | 848 | 11.4 | 117 | 5.3 | 174 | 11.5 | 8 | 16.7 |
| | *Melanogrammus aeglefinus* | Haddock | | | 24 | 0.3 | | | | | | |
| | *Merlangius merlangus* | Whiting | 2 | <0.1 | 936 | 12.6 | 52 | 2.4 | | | | |
| | *Micromesistius poutassou* | Blue whiting | | | 174 | 2.3 | | | | | | |
| | *Pollachius virens* | Saithe | | | 21 | 0.3 | | | | | | |
| | *Trisopterus esmarkii* | Norway pout | | | 1751 | 23.6 | | | | | | |
| | *Trisopterus minutus* | Poor cod | | | 376 | 5.1 | 28 | 1.3 | | | | |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *Gadids sp.* | Unidentified gadids | | | | | | | | | | |
| Gobiidae | *Gobius niger* | Black goby | 3621 | 29.6 | 131 | 1.8 | | | 228 | 15.1 | | |
| | *Neogobius melanostomus* | Round goby | | | | | | | 4 | 0.3 | | |
| | *Pomatoschistus minutus* | Sand goby | 3622 | 29.6 | | | | | 2 | 0.1 | | |
| | Gobiids sp. | Unidentified gobies | | | 10 | 0.1 | 3 | 0.1 | | | | |
| Labridae | *Ctenolabrus rupestris* | Goldsinny wrasse | | | 31 | 0.4 | | | 24 | 1.6 | | |
| | *Labrus bergylta* | Ballan wrasse | | | 14 | 0.2 | | | | | | |
| | *Labrus mixtus* | Cuckoo wrasse | | | 18 | 0.2 | | | | | | |
| | *Labrids sp.* | Unidentified wrasses | | | | | | | | | | |
| Lotidae | *Molva molva* | Ling | | | 16 | 0.2 | | | | | | |
| Merlucciidae | *Merluccius merluccius* | Hake | | | 5 | 0.1 | | | | | | |
| Percidae | *Gymnocephalus cernua* | Ruffe | | | | | | | 2 | 0.1 | | |
| Pholidae | *Pholis gunnellus* | Butterfish | 10 | 0.1 | | | | | 6 | 0.4 | | |
| Pleuronectidae | *Glyptocephalus cynoglossus* | Witch | | | 3 | <0.1 | | | | | | |
| | *Hippoglossoides platessoides* | American plaice | | | 70 | 0.9 | | | | | | |
| | *Limanda limanda* | Dab | 16 | 0.1 | 14 | 0.2 | 824 | 37.7 | 95 | 6.3 | | |
| | *Microstomus kitt* | Lemon sole | | | 156 | 2.1 | | | | | | |
| | *Platichthys flesus* | European flounder | 180 | 1.5 | 17 | 0.2 | 121 | 5.5 | 42 | 2.8 | 8 | 16.7 |
| | *Pleuronectes platessa* | Plaice | 486 | 4.0 | 44 | 0.6 | 130 | 5.9 | 27 | 1.8 | | |
| | Pleuronectids sp. | Unidentified pleuronectids | | | | | 3 | 0.1 | 40 | 2.6 | | |
| Salmonidae | *Coregonus lavaretus* | European whitefish | | | | | | | | | 8 | 16.7 |
| Scombridae | *Scomber scombrus* | Atlantic mackerel | | | 2 | <0.1 | | | | | | |
| Scophthalmidae | Scophthalmus maximus | Turbot | | | | | | | | | 4 | 8.3 |
| Solenidae | *Solea solea* | Sole | 6 | <0.1 | | | | | 2 | 0.1 | | |
| Sternoptychidae | *Maurolicus muelleri* | Mueller's pearlside | | | 67 | 0.9 | | | | | | |
| Stichaeidae | *Lumpenus lampretaeformis* | Snakeblenny | | | 1 | <0.1 | | | | | | |
| Zoarcidae | *Lycenchelys sarsi* | Sars' eelpout | | | 3 | <0.1 | | | | | | |
| | *Zoarces viviparus* | Viviparous eelpout | 1625 | 13.3 | 286 | 3.9 | | | 54 | 3.6 | | |
| Unidentified | *unidentified* | Unidentified sp. | 17 | 0.1 | 59 | 0.8 | | | | | | |
| | | **Total:** | 12245 | 100.0 | 7408 | 100.0 | 2187 | 100.0 | 1513 | 100.0 | 48 | 100.0 |

# Appendix F

**Appendix F: Geographic variations in the grey seals (*Halichoerus grypus*) diet shown as the total count of otoliths recovered and as a percentage of each fish species frequency of occurrence out of the total otolith count within each geographic area. Fish species only indicated with a "p" for presence in the grouped data have been removed from this part of the analysis because frequency of occurrence cannot be calculated. "Areas on the map" refers to fig. 1. Where; D: Southwestern Baltic Sea; F: Gotland; G: Swedish Baltic Sea; H: Finnish Baltic Sea; I: Gulf of Finland; J: Gulf of Bothnia.**

| **Fish species:** | | **Areas on the map:** | **D** | | **F** | | **G** | | **J** | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Family:** | **Scientific name:** | **Common name:** | **Total number of otoliths found** | **%** | **Total number of otoliths found** | **%** | **Total number of otoliths found** | **%** | **Total number of otoliths found** | **%** |
| Ammodytidae | *Ammodytes tobianus* | Lesser sand eel | 1 | 3.2 | | | | | | |
| | *Ammodytes sp.* | Unidentified sand lances | | | | | 116 | 1.2 | | |
| Anguillidae | *Anguilla anguilla* | European eel | 1 | 3.2 | | | 52 | 0.5 | | |
| Clupeidae | *Clupea harengus* | Atlantic herring | | | 173 | 32.6 | 6908 | 70.4 | 906 | 24.4 |
| | *Sprattus Sprattus* | Sprat | | | 166 | 31.3 | 926 | 9.4 | 34 | 0.9 |
| Cottidae | *Myoxocephalus quadricornis* | Fourhorn sculpin | | | | | 12 | 0.1 | | |
| | *Myoxocephalus scorpius* | Shorthorn sculpin | | | 15 | 2.8 | 6 | 0.1 | | |
| | *Taurulus bubalis* | Long-spined sea scorpion | | | | | 8 | 0.1 | | |
| | *Cottids sp* | Unidentified sculpins | | | | | 2 | <0.1 | | |
| Cyclopteridae | *Cyclopterus lumpus* | Lumpsucker | | | | | 2 | <0.1 | | |
| Cyprinidae | *Rutilus rutilus* | Roach | | | | | | | 10 | 0.3 |
| | *Cyprinids sp.* | Unidentified carps | | | | | 156 | 1.5 | 134 | 3.6 |
| Esocidae | *Esox lucius* | Northern pike | | | | | 14 | 0.1 | | |
| Gadidae | *Gadus morhua* | Atlantic cod | | | 130 | 24.5 | 214 | 2.2 | | |
| Gasterosteidae | *Gasterosteus aculeatus* | Three-spined stickleback | | | | | | | 4 | 0.1 |
| | *Gasterosteides sp.* | Unidentified sticklebacks | | | 12 | 2.3 | | | | |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Gobiidae | *Gobius niger* | Black goby | 12 | 38.7 | | | | | | |
| | *Gobiusculus flavescens* | Two-spotted goby | | | | | 38 | 0.4 | | |
| | *Neogobius melanostomus* | Round goby | 9 | 29.0 | | | | | | |
| | *Pomatoschistus minutus* | Sand goby | 1 | 3.2 | | | | | | |
| | Gobiids sp. | Unidentified gobies | | | 10 | 1.9 | 14 | 0.1 | | |
| Lotidae | *Enchelyopus cimbrius* | Fourbeard rockling | | | | | 8 | <0.1 | | |
| | *Lota lota* | Burbot | | | | | 4 | <0.1 | 8 | 0.2 |
| Merlucciidae | *Merluccius merluccius* | Hake | 1 | 3.2 | | | | | | |
| Osmeridae | *Osmerus eperlanus* | Smelt | | | | | 170 | 1.7 | 64 | 1.7 |
| Percidae | *Gymnocephalus cernua* | Ruffe | | | | | 18 | 0.2 | | |
| | *Perca fluviatilis* | Perch | | | | | 42 | 0.4 | 36 | 1.0 |
| | *Sander lucioperca* | Zander | | | | | 2 | <0.1 | | |
| Petromyzontidae | *Lampetra fluviatilis* | River lamprey | | | | | | | 4 | 0.1 |
| Pleuronectidae | *Limanda limanda* | Dab | 3 | 9.7 | | | 42 | 0.4 | | |
| | *Microstomus kitt* | Lemon sole | 1 | 3.2 | | | | | | |
| | *Platichthys flesus* | European flounder | | | 15 | 2.8 | 104 | 1.1 | | |
| | *Pleuronectes platessa* | Plaice | 2 | 6.5 | | | 2 | <0.1 | | |
| Salmonidae | *Coregonus albula* | Vendace | | | | | 14 | 0.1 | 1368 | 36.8 |
| | *Coregonus lavaretus* | European whitefish | | | | | 414 | 4.2 | 296 | 8.0 |
| | *Salmo salar* | Atlantic salmon | | | | | 76 | 0.8 | 30 | 0.8 |
| | *Salmo trutta* | Brown trout | | | | | 36 | 0.4 | 146 | 3.9 |
| | *Salmo sp.* | Unidentified salmonids | | | | | 4 | <0.1 | 18 | 0.5 |
| | *Coregonus sp.* | Unidentified *Coregonus sp.* | | | | | | | 294 | 7.9 |
| Scophthalmidae | Scophthalmus maximus | Turbot | | | 3 | 0.6 | 44 | 0.4 | | |
| Zoarcidae | *Zoarces viviparus* | Viviparous eelpout | | | 6 | 1.1 | 254 | 2.6 | | |
| Unidentified | Unidentified | Unidentified sp. | | | | | 106 | 1.0 | 364 | 9.8 |
| | | **Total:** | 31 | 100.0 | 530 | 100.0 | 9808 | 100.0 | 3716 | 100.0 |

# Appendix G

**Appendix G: Geographic variations in the Baltic ringed seals (*Pusa hispida*) diet shown as the total count of otoliths recovered and as a percentage of each fish species frequency of occurrence out of the total otolith count within each geographic area. Fish species only indicated with a "p" for presence in the grouped data have been removed from this part of the analysis because frequency of occurrence cannot be calculated. "Areas on the map" refers to fig. 1. Where; H: Finnish Baltic Sea; I: Gulf of Finland; J: Gulf of Bothnia.**

| **Fish species:** | | **Areas on the map:** | **J** | |
|---|---|---|---|---|
| **Family:** | **Scientific name:** | **Common name:** | **Total number of otoliths found** | **%** |
| Ammodytidae | *Ammodytes sp.* | Unidentified sand lances | 72 | 1.6 |
| Anguillidae | *Anguilla anguilla* | European eel | 10 | 0.2 |
| Clupeidae | *Clupea harengus* | Atlantic herring | 608 | 13.6 |
| Cottidae | *Myoxocephalus quadricornis* | Fourhorn sculpin | 46 | 1.0 |
| | *Myoxocephalus scorpius* | Shorthorn sculpin | 24 | 0.5 |
| Gadidae | *Gadus morhua* | Atlantic cod | 26 | 0.6 |
| Gasterosteidae | *Gasterosteus aculeatus* | Three-spined stickleback | 3304 | 73.8 |
| Osmeridae | *Osmerus eperlanus* | Smelt | 98 | 2.2 |
| Percidae | *Gymnocephalus cernua* | Ruffe | 12 | 0.3 |
| Salmonidae | *Coregonus albula* | Vendace | 116 | 2.6 |
| | *Coregonus lavaretus* | European whitefish | 106 | 2.4 |
| | *Salmo salar* | Atlantic salmon | 22 | 0.5 |
| | *Salmo trutta* | Brown trout | 16 | 0.4 |
| Zoarcidae | *Zoarces viviparus* | Viviparous eelpout | 14 | 0.3 |
| | | **Total:** | 4474 | 100.0 |

# Appendix H

**Appendix H: Comparison of the three seal species; harbour seals (*Phoca vitulina*), grey seals (*Halichoerus grypus)* and Baltic ringed seals (*Pusa hispida*) diets from different geographic areas where samples from more than one seal species occurred. The squares highlighted with grey indicates that the fish species have been found at least once in the samples from that area. If the squares are blank, this indicates that the fish species have not been found in any samples from that site. The frequency of occurrence out of the total count of otoliths recovered from each seal species within each area is shown where this was possible to calculate. "Areas on the map" refers to fig. 1. Where; D: Southwestern Baltic Sea; H: Finnish Baltic Sea; I: Gulf of Finland; J: Gulf of Bothnia.**

| | | **Areas on the map:** | **D** | | **H** | | **I** | | **J** | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Fish species:** | | **Seal species:** | **Harbour seal** | **Grey seal** | **Grey seal** | **Baltic ringed seal** | **Grey seal** | **Baltic ringed seal** | **Grey seal** | **Baltic ringed seal** |
| **Family** | **Scientific name:** | **Common name:** | **Presence/ absence** | **Presence/ absence** | **Presence/ absence** | **Presence/ absence** | **Presence/ absence** | **Presence/ absence** | **Presence/ absence** | **Presence/ absence** |
| Ammodytidae | *Ammodytes tobianus* | Lesser sand eel | 44.5% | 3.2% | | | | | | |
| | *Hyperoplus lanceolatus* | Greater sand eel | 0.3% | | | | | | | |
| | *Ammodytes sp.* | Unidentified sand lances | | | | | | | | 1.6% |
| Anguillidae | *Anguilla anguilla* | European eel | | 3.2% | | | | | | 0.2% |
| Belonidae | *Belone belone* | Garfish | 0.9% | | | | | | | |
| Clupeidae | *Clupea harengus* | Atlantic herring | 5.3% | | | | | | 24.4% | 13.6% |
| | *Sprattus sprattus* | Sprat | 2.0% | | | | | | 0.9% | |
| Cottidae | *Myoxocephalus quadricornis* | Fourhorn sculpin | | | | | | | | 1.0% |
| | *Myoxocephalus scorpius* | Shorthorn sculpin | | | | | | | | 0.5% |
| | *Taurulus bubalis* | Long-spined sea scorpion | 0.3% | | | | | | | |
| | *Cottids sp* | Unidentified sculpins | | | | | | | | |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Cyprinidae | *Blicca bjoerkna* | White bream | | | | | | | | |
| Cyprinidae | *Rutilus rutilus* | Roach | 0.1% | | | | | | 0.3% | |
| | *Cyprinids sp.* | Unidentified carps | | | | | | | 3.6% | |
| Gadidae | *Enchelyopus cimbrius* | Four-bearded rockling | 0.4% | | | | | | | |
| | *Gadus morhua* | Atlantic cod | 11.5% | | | | | | | 0.6% |
| Gasterosteidae | *Gasterosteus aculeatus* | Three-spined stickleback | | | | | | | 0.1% | 73.8% |
| Gobiidae | *Gobius niger* | Black goby | 15.1% | 38.7% | | | | | | |
| | *Neogobius melanostomus* | Round goby | 0.3% | 29.0% | | | | | | |
| | *Pomatoschistus minutus* | Sand goby | 0.1% | 3.2% | | | | | | |
| Labridae | *Ctenolabrus rupestris* | Goldsinny wrasse | 1.6% | | | | | | | |
| Lotidae | *Lota lota* | Burbot | | | | | | | 0.2% | |
| Merlucciidae | *Merluccius merluccius* | Hake | | 3.2% | | | | | | |
| Osmeridae | *Osmerus eperlanus* | Smelt | | | | | | | 1.7% | 2.2% |
| Percidae | *Gymnocephalu s cernua* | Ruffe | 0.1% | | | | | | | 0.3% |
| | *Perca fluviatilis* | Perch | | | | | | | 1.0% | |
| | *Percids sp.* | Unidentified percids | | | | | | | | |
| Petromyzontidae | *Lampetra fluviatilis* | River lamprey | | | | | | | 0.1% | |
| Pholidae | *Pholis gunnellus* | Butterfish | 0.4% | | | | | | | |
| Pleuronectidae | *Limanda limanda* | Dab | 6.3% | 9.7% | | | | | | |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | *Microstomus kitt* | Lemon sole | | 3.2% | | | | | | |
| | *Platichthys flesus* | European flounder | 2.8% | | | | | | | |
| | *Pleuronectes platessa* | Plaice | 1.8% | 6.5% | | | | | | |
| | Pleuronectids sp. | Unidentified pleuronectids | 2.6% | | | | | | | |
| Salmonidae | *Coregonus albula* | Vendace | | | | | | | 36.8% | 2.6% |
| | *Coregonus lavaretus* | European whitefish | | | | | | | 8.0% | 2.4% |
| | *Salmo salar* | Atlantic salmon | | | | | | | 0.8% | 0.5% |
| | *Salmo trutta* | Brown trout | | | | | | | 3.9% | 0.4% |
| | *Salmo sp.* | Unidentified salmonids | | | | | | | 0.5% | |
| | *Coregonus sp.* | Unidentified *Coregonus sp.* | | | | | | | 7.9% | |
| Solenidae | *Solea solea* | Sole | 0.1% | | | | | | | |
| Zoarcidae | *Zoarces viviparus* | Viviparous eelpout | 3.6% | | | | | | | 0.3% |
| | | **Total species found:** | **21** | **9** | **17** | **5** | **9** | **7** | **17** | **20** |