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# Prey choice of great cormorants (*Phalacrocorax carbo*) in a marine protected area

Potential impact on collapsed fish stocks and  
implications for future monitoring

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## Abstract

Great cormorant (*Phalacrocorax carbo*) populations have experienced a rapid growth in Europe since the 1980s, resulting in conflicts with fisheries over local fish resources. The 8-fjords area is a marine protected area on the Swedish west coast, where long term overfishing has led to a collapse of several local demersal fish stocks. Subsequently, fishing regulations have been implemented to protect and re-establish the stocks of cod- and flatfish species, at the same time as cormorants have increased largely in numbers. The increased predation pressure has raised concerns about the recovery of local fish stocks, although knowledge about cormorant feeding habits are lacking. Here, cormorant prey choice in two subareas of the 8-fjords area is investigated, using morphological identification of prey remains in regurgitated pellets. An estimated 15 077 fishes were identified from a total of 480 pellets. The most important prey families based on relative abundance were flatfish (Pleuronectidae 48%), gobies (Gobiidae 21%) and codfish (Gadidae 13%). Pairwise ANOSIM analyses showed extremely small differences in diet composition between sites ( $p \leq 0.003$ ,  $R < 0.08$ ). In comparison to available monitoring fishery data, the diet did not correspond to prey abundance. Estimated fish sizes of a subsample of flat- and codfish showed that juveniles seemed to be preferred. Pellet analysis provided limited information about consumed species and should be combined with other methods for more detailed assessments of cormorant prey choice in the 8-fjords area.

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# Introduction

## Cormorant development

Great cormorants (*Phalacrocorax carbo*) have increased substantially in Europe during the past decades, with the largest growth occurring between 1980 and mid 1990s (Lindell *et al.* 1995, Engström 2001a). Three sub-species of great cormorants are breeding in Europe, *Phalacrocorax carbo carbo*, *Phalacrocorax carbo sinensis* and *Phalacrocorax carbo norvegicus* (Bregnballe *et al.* 2014). The latter has recently been discovered as a third sub-species, breeding in Norway and along the coasts from Sweden to France (Marion & Le Gentil 2006). It has not been distinguished in cormorant inventories due to limited information on colonies (Bregnballe *et al.* 2014) and therefore, only *P. c. carbo* and *P. c. sinensis* are further mentioned and distinguished here. Individuals of *P. c. carbo* and *P. c. sinensis* appear similar and are difficult to separate when they co-occur, although they can be distinguished during breeding season by their choice of breeding habitats. *P. c. carbo* only breed in marine coastal habitats in the North Atlantic and colonize mainly along the coasts of Ireland, UK, Iceland, Norway and France (Bregnballe *et al.* 2014). In 2012, the number of *P. c. carbo* was estimated to 42 500 breeding pairs (Bregnballe *et al.* 2014). *P. c. sinensis* colonize along coasts and in inland lakes with a large distribution over Europe (figure 1). Populations of this sub-species have rebounded from near extinction in Europe to an estimated total number of 219 400 breeding pairs in 2012 (Bregnballe *et al.* 2014, European Commission 2016).

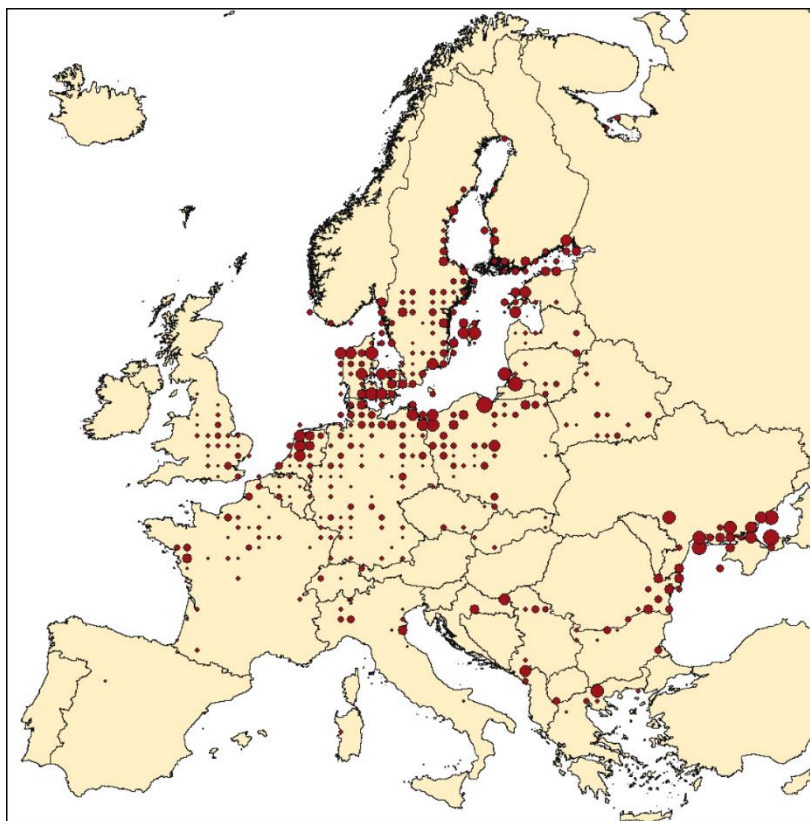


Figure 1. Map showing distribution and relative sizes of great cormorant (*Phalacrocorax carbo sinensis*) colonies in Europe 2012. Source: van Eerden *et al.* (2012).

In the beginning of the 1900s, *P. c. sinensis* had nearly become extinct in Europe as a consequence of human persecution (Lindell *et al.* 1995). Only a few, small populations were able to persist in central and eastern Europe as the persecution ceased when cormorant numbers

were low (Lindell *et al.* 1995). During the first half of the century, the surviving populations managed to spread but remained scarce and low in numbers (Lindell *et al.* 1995). The large increase of cormorant populations began in the mid-1980s, when populations across Europe simultaneously started to grow rapidly (Lindell *et al.* 1995). The reason for this sudden success was partly because protective legislation was implemented, but also because cormorant resources became more abundant (Lindell *et al.* 1995). In 1979, great cormorants became protected under Directive 79/409/EEC on the conservation of wild birds, which included creation of protective areas where cormorants colonized during breeding season, as well as implementation of restrictive hunting laws. It is also believed that the eutrophication of lakes and coastal waters in Europe enabled the large population growth, as an increase in primary production, increased cormorant resources (Lindell *et al.* 1995).

In Sweden, cormorants became extinct around 1890 and did not return until 1948, when a colony of *P. c. sinensis* re-established on the east coast (Lindell *et al.* 1995, Engström & Wirdheim 2014). The population remained on the east coast for decades, but started to spread and colonize along the coasts and in southern inland lakes at the end of the 1980s (Engström & Wirdheim 2014). Inventories on current numbers are lacking and existing numbers are rough estimates as the resolution of counts is limited, but during the latest national inventory in 2012 the population of breeding *P. c. sinensis* seemed to have reached a maximum and stabilized at around 40 000 breeding pairs (Engström & Wirdheim 2014).

## Cormorant conflict

The rapid growth of cormorant populations has caused a growing conflict with fisheries, as competitors of important fish species (Vetemaa *et al.* 2010, Salmi *et al.* 2015, Lehtikoinen *et al.* 2017). Cormorants are considered generalists and opportunistic piscivorous predators, which means that they adjust their diet to prey availability and can prey on fish from several trophic levels and many different habitats. Cormorants have an estimated daily consumption rate of 14-37 % of their own weight, which corresponds to a food intake of around 0.5 kg per day among adult birds, although the number differs between seasons and species (Nelson 2005, Ridgway 2010). When cormorant populations grow and the predation pressure on local fish stock increases, concerns are raised that local stocks of commercially valuable fish species are reduced. The conflict includes direct competition where the fish species and sizes in cormorant diet overlap with the fishery catches, as well as indirect competition where cormorants prey on smaller fish sizes and thereby may reduce the recruitment to larger fish sizes. Numerous studies on the effects of cormorant predation on fish stocks have been conducted in many different areas and habitats with contrasting conclusions (e.g. Vetemaa *et al.* 2010, Östman *et al.* 2012, Engström 2001b, Lehtikoinen *et al.* 2011). In areas where fish stocks are reduced, it has been suggested that size-selective predation from cormorants could have a negative effect on fish recruitment (Barrett *et al.* 1990). A recent meta-analysis concluded that cormorants have a negative impact on fish populations, but that the effect differs depending on prey species and areas (Ovegård 2017). Cormorant prey choice and potential impact on local fish stocks depend on the environmental conditions and fish community composition in each area, as well as seasonal variability in prey distribution and cormorant life stages (Boström *et al.* 2012a, Emmrich & Düttmann 2011, Östman *et al.* 2013, Gagliardi *et al.* 2015). Potential impact on local fish stocks in different areas thus needs to be assessed separately to account for spatial differences.

## The 8-fjords area

The 8-fjords area is a marine protected area on the Swedish west coast that consists of 8 fjords around the Orust and Tjörn islands (figure 2). The northern part of the 8-fjords area (Havstensfjorden) has had a high activity of commercial fishing, where the catches of cod

(*Gadus morhua*) and plaice (*Pleuronectes platessa*) has been especially high (Svedäng *et al.* 2016). Long term, high fishing pressure in the area has caused a successive decline of the local fish stocks, which has ultimately led fisheries in the area to close (Svedäng & Bardon 2003, Svedäng 2003, Cardinale *et al.* 2012, Svedäng *et al.* 2016). In the beginning of the 2000s, it was concluded that overfishing had caused a collapse of the demersal fish stock, with a severe reduction of large individuals of cod- and flatfish species in the area, suggesting that the local fish stocks were depending on individuals from off-shore stock as recruitment sources (Svedäng & Bardon 2003, Svedäng 2003, Svedäng *et al.* 2016).

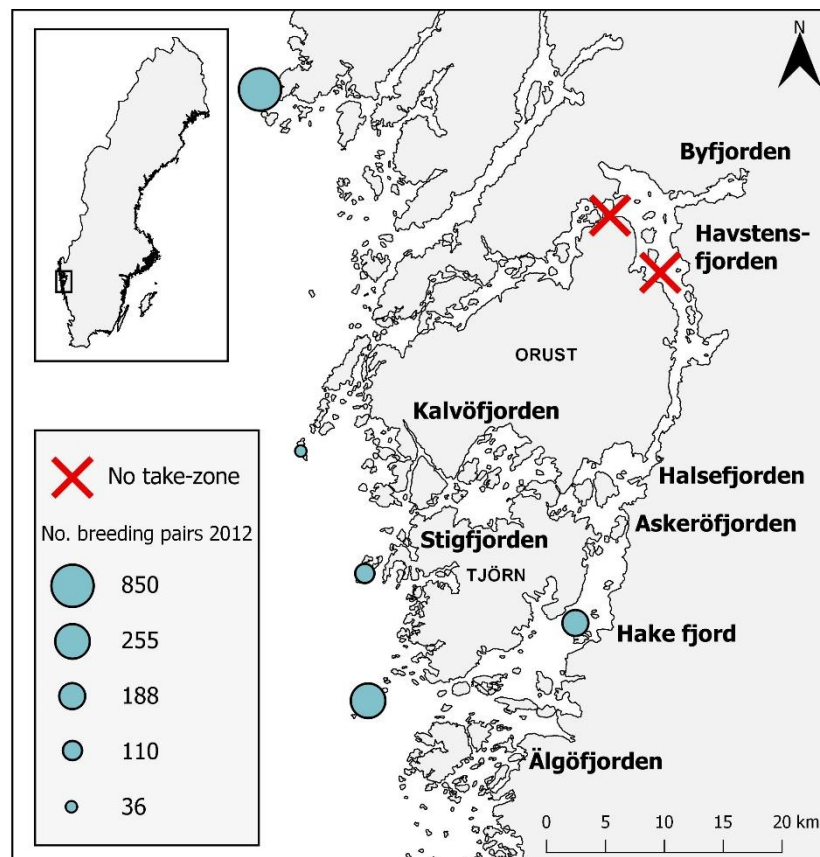


Figure 2. The 8-fjords area. Locations and sizes of nearby colonies and locations of no take-zones in Havstensfjorden. Background data from the Swedish National Land Survey (open map data).

Following the collapse, several fishing regulations have gradually been implemented within the 8-fjords area, in attempts to recover the collapsed fish stocks (Svedäng *et al.* 2016). The regulations have included a ban on seine fishing, restrictions for net fishing and a daily bag limit for cod, haddock (*Melanogrammus aeglefinus*) and pollack (*Pollachius pollachius*, Svedäng *et al.* 2016). In 2010, the demersal fish stocks had not shown any signs of recovery and new restrictive fishing regulations were implemented in the northern part of the 8-fjords area (Svedäng *et al.* 2016). Two no-take zones were implemented in Havstensfjorden where cod spawning sites have been observed, one for the whole year and one for October through March (Svedäng *et al.* 2016). The area surrounding the no-take zones in Havstensfjorden and the surrounding fjords (By-, Halse-Askerö-, Kalvö- and Stigfjorden) serve as buffer zones, where fishing for cod, haddock and pollack is banned and fishing for other species is only allowed using manual gear and crustacean pots (Svedäng *et al.* 2016). The zones are implemented with emphasis on protecting the stock of cod and its spawning sites, but the overall aim of the regulations is to enable the recovery of several demersal fish stocks, using cod, haddock (*Melanogrammus aeglefinus*), pollack (*Pollachius pollachius*), plaice and turbot

(*Scophthalmus maximus*) as target species for the recovery (Svedäng *et al.* 2016). As of today, there have been no indication of a recovery and concerns about predation from cormorants, together with seals, is sometimes expressed as one explanatory factor (Svedäng *et al.* 2016, Bryhn *et al.* 2016).

### Cormorants in the 8-fjords area

Cormorants started to colonize the Swedish west coast in 1994 (Järås 2010). In 2012, the number of breeding cormorants on the west coast seemed to have stabilized at around 3000 pairs (Engström & Wirdheim 2014). In Hake fjord, within the 8-fjords area, one colony of two breeding pairs established in 2002 and had grown to 188 breeding pairs in 2012 (Järås 2010, Engström & Wirdheim 2014). Small colonies also established on the coast, outside the 8-fjords area in the beginning of the 2000s which grew rapidly the subsequent years (Järås 2010). The number of wintering cormorants has also increased since the colonization on the west coast (van Eerden *et al.* 2012, Skov *et al.* 2011). During winter, both sub-species occur in the area. *P. c. carbo* populations breeding in Norway migrate south to the Swedish west coast during winter and *P. c. sinensis* breeding further north occur as wintering birds in the area, while *P. c. sinensis* breeding in the area either stay on the west coast or migrate south (van Eerden *et al.* 2012, Skov *et al.* 2011).

### Cormorant prey choice in the 8-fjords area

Cormorant prey choice has not been comprehensively studied in the 8-fjords area. One previous study investigated cormorant diet in Hake fjord between 2001-2002 (Lunneryd & Alexandersson 2005). However, no recent studies have been conducted in the area and therefore, knowledge about cormorant prey choice is limited and the potential effect on the protected fish stock in the 8-fjords area is unknown.

The fish community composition differs between subareas of the 8-fjords area where the northern part has a lower biodiversity and species abundance than the southern part (Andersson *et al.* 2013, Bergström *et al.* 2016). Given the differences in fish community composition within the 8-fjords area and the opportunistic feeding strategy of cormorants, it is probable that the prey choice and potential impact on fish stocks differ between subareas.

A common method to investigate cormorant diet is to use regurgitated material (pellets) (Barret *et al.* 2007). Adult cormorants produce on average one pellet per day that contains non-digestible prey remains, such as otoliths and bone parts (Zijlstra & van Eerden 1995). These pellets can be collected from cormorant roosting sites and prey remains can be extracted and identified. A potential bias of this method is secondary consumption, where prey of prey is found in diet analysis (Oehm *et al.* 2016). This possibility can be assessed by investigating co-occurrence of piscivorous fish taxa and other taxa in pellets.

### Aim of study

The aim of this study was to fill the existing knowledge gaps about cormorant prey choice in the 8-fjords area, which is crucial for subsequent assessment of potential impact on fish stocks. The objectives were to (i) gain knowledge of cormorant diet in the 8-fjords area, (ii) detect potential differences in diet between subareas and (iii) compare cormorant diet to available monitoring fishery data in prey abundance and length distribution. Information on differences in prey choice between subareas will create a foundation for decisions about the spatial resolution of possible future dietary sampling programmes. Overlaps between diet and available monitoring fishery data may indicate that prey choice could be an effect of prey availability in the area.

## Materials and methods

### Field sampling

Cormorant pellets were collected from two roosting sites in Havstensfjorden and two roosting sites in Halse-Askeröfjorden (figure 3). Each site was visited four times between 31 August and 20 October 2016. All pellets found at the site on each sampling occasion were wrapped in plastic foil and stored in -20°C until analysis.

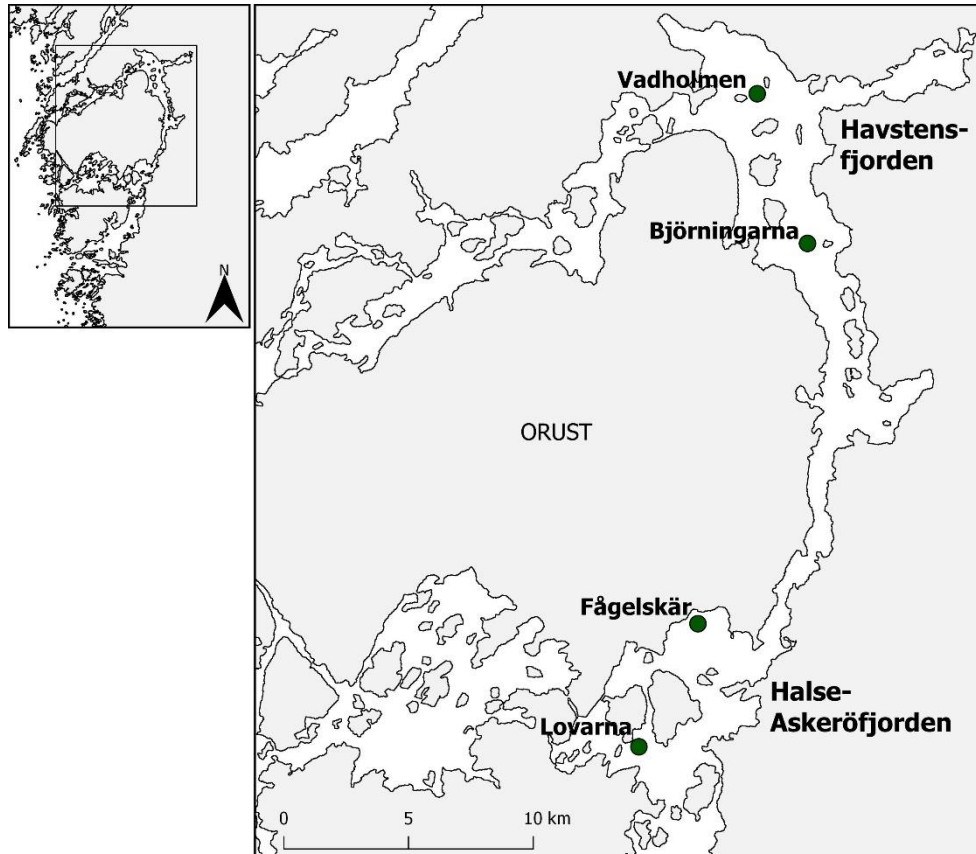


Figure 3. Roosting sites within the restricted fishing area where pellets were collected. Background data from the Swedish National Land Survey (open map data).

### Pellet analysis

A total of 120 pellets per site (30 per collection date) were randomly selected for analysis. Empty pellets were excluded from further analysis and substituted by pellets containing prey remains. Each pellet was dissolved in water for a minimum of one day and then rinsed thoroughly. Fish hard parts were separated from other pellet content and air-dried on a petri dish. Identification of fish hard parts was done using reference literature (Härkönen 1986, Leopold *et al.* 2001, Watt *et al.* 1997) and a reference collection of otoliths. The total number of fish per taxon was estimated by dividing the number of otoliths by two. Relative abundance was calculated from the numerical proportions of a taxon in each pellet. Frequency of occurrence was calculated from the number of pellets containing a taxon divided by the total number of pellets containing prey remains. Potential secondary consumption was examined from co-occurrence of piscivorous predators and other taxa in pellets.



## Statistical analyses

Due to limitations in identification of fish hard parts to species level, caused by digestive erosion, the statistical analyses were based on fish families. The data were square-root transformed prior to statistical analyses to downweigh the relative importance of the most common taxa. To visualize diet overlaps or differences between sites, a non-metric multidimensional scaling analysis (nMDS) was performed using Bray-Curtis dissimilarity matrix (Bray & Curtis 1957). To test for significant differences in diet composition between sites, pairwise ANOSIM tests were conducted. Differences in length distributions of cod- and flatfish between subareas in the diet were tested using a Wilcoxon rank sum test. All analyses were done in R studio (R Core Team 2017). nMDS and ANOSIM were conducted in ‘vegan’ package (Oksanen *et al.* 2017).

## Comparison to available monitoring fishery data

The diet was compared to available monitoring fishery data in the respective subarea. Data from a yearly trawling survey conducted in September 2016 (Ytreberg *et al.* 2014) and a fyke net survey conducted in 2012 (Bergström *et al.* 2016) was used. The trawling survey was conducted with one trawl haul per subarea, using a mesh size of 16 mm, at bottom depths of 15 m in Havstensfjorden and 21 m in Halse-Askeröfjorden (Ytreberg *et al.* 2014). The fyke nets had a mesh size of 11 mm and was randomly distributed at depths up to 10 m (Bergström *et al.* 2016). The relative abundance of fish families caught in each survey was compared to the relative abundance of families in the diet. Sizes of fish from the cod- and flatfish families found in the monitoring fishery surveys was compared to estimated fish sizes in the diet.

## Fish size estimates

Fish size estimates were made from measurements for a subsample of cod- and flatfish otoliths. For each site, 30 otoliths per family were randomly selected and measured. Due to difficulty in determining otoliths to species level, an average family size regression equation was calculated for each family. Estimates were based on species specific size regression equations  $FL = a + b * OW$  (FL = fish length, OW = otolith width, Leopold *et al.* 2001), where mean of constants  $a$  and  $b$  for species occurring in the area was calculated to get an average family size regression equation.

## Results

### Field sampling

Pellets were collected on four occasions on Fågelskär and Lovarna, three occasions on Björningarna and two occasions on Vadholmen.

### Pellet analysis

A total of 559 pellets were analysed, where 79 were empty and excluded from further analysis. From the 480 pellets containing prey remains, 31 071 otoliths were found, out of which 999 could not be identified. A total of 17 families were identified, where 15 species could be determined (table 1). Two fresh water families, carp (Cyprinidae) and perch (Percidae), were found in 14 pellets. The total number of fish was estimated to 15 077.

Table 1. Estimated number of fish, relative abundance and frequency of occurrence (FO) of taxa in diet.

Family	Species	Estimated number	%Relative abundance	%FO
Anguillidae	European eel, <i>Anguilla anguilla</i>	12	0.97	2.50
Unidentified	Unidentified	-	5.15	32.29
Bothidae	Scaldfish, <i>Arnoglossus laterna</i>	16	0.11	3.96
Callyonymidae	Common dragonet, <i>Callionymus lyra</i>	5	0.05	0.83
Clupeidae	Unidentified	733	2.41	10.42
Cottidae	Shortshorn sculpin, <i>Myoxocephalus scorpius</i>	59	0.93	7.71
	Longspined bullhead, <i>Taurulus bubalis</i>	3	0.12	1.04
	Unidentified	92	2.39	11.04
	Total Cottidae	154	3.48	18.54
Cyprinidae	Unidentified	143	1.44	2.29
Gadidae	Whiting, <i>Merlangius merlangus</i>	97	0.45	0.01
	Tadpole fish, <i>Raniceps raninus</i>	1	0.01	0.20
	Unidentified	1228	12.91	50.00
	Total Gadidae	1326	13.38	50.63
Gasterosteidae	Three-spined stickleback, <i>Gasterosteus aculeatus</i>	30	0.12	1.46
Gobiidae	Black goby, <i>Gobius niger</i>	3824	20.20	61.46
	Unidentified	275	0.95	7.92
	Total Gobiidae	4098	21.15	63.75
Labridae	Unidentified	198	1.43	12.08
Lotidae	Ling, <i>Molva molva</i>	1	0.01	0.21
Percidae	Perch, <i>Perca fluviatilis</i>	9	0.06	0.63
Pleuronectidae	American plaice, <i>Hippoglossoides platessoides</i>	3	0.02	0.21
	Dab, <i>Limanda limanda</i>	380	4.86	26.88
	Unidentified	7824	43.51	72.71
	Total Pleuronectidae	8206	48.39	74.58
Salmonidae	Unidentified	58	0.69	3.75
Scophthalmidae	Unidentified	5	0.03	1.04
Soleidae	Sole, <i>Solea solea</i>	52	0.95	9.17
Zoarcidae	Eelpout, <i>Zoarces viviparus</i>	29	0.20	4.58

The most common prey families were flatfish (Pleuronectidae), gobies (Gobiidae) and codfish (Gadidae) (figure 4).

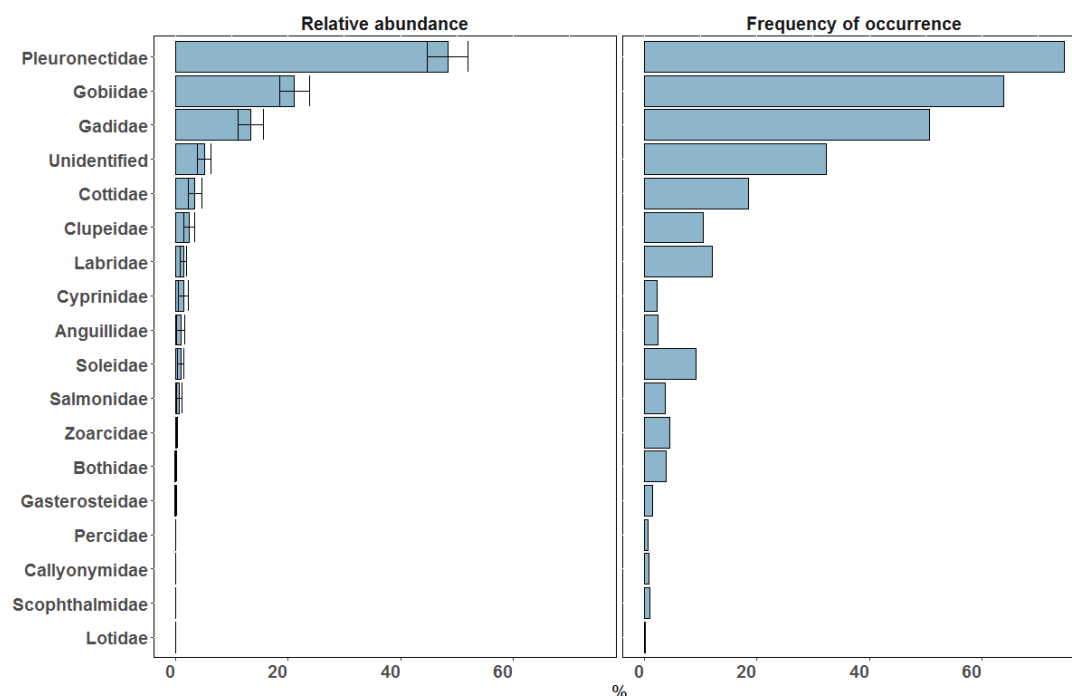


Figure 4. Relative abundance ( $\pm 95\%$  confidence intervals) and frequency of occurrence of families in cormorant diet.

## Statistical analyses

The nMDS analysis showed no clear patterns of differences between sites (figure 5).

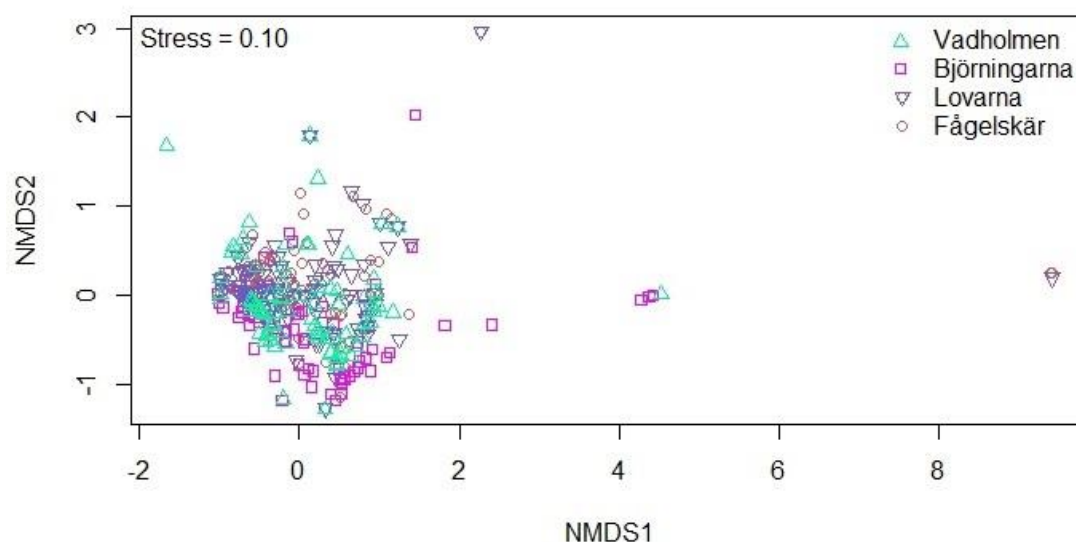


Figure 5. nMDS plot of square-root transformed prey abundance data in the diet. Outliers to the right ( $n=3$ ) represent samples containing only freshwater species.

Pairwise ANOSIM tests showed extremely small differences in diet composition between sites ( $p < 0.003$ ,  $R < 0.08$ , permutations=999).

## Comparison to available monitoring fishery data

### Prey abundance

In Havstensfjorden, 10 families were found in the fyke net survey from 2012 whereas 4 families were found in the trawl survey from 2016. The most common families in the fyke net survey were eel (*Anguillidae*), wrasses (*Labridae*), flatfish and eelpout (*Zoarcidae*). The most common families in the trawl survey were flatfish, codfish and turbot (*Scophthalmidae*). In the diet, flatfish and gobies were the most common families (figure 6).

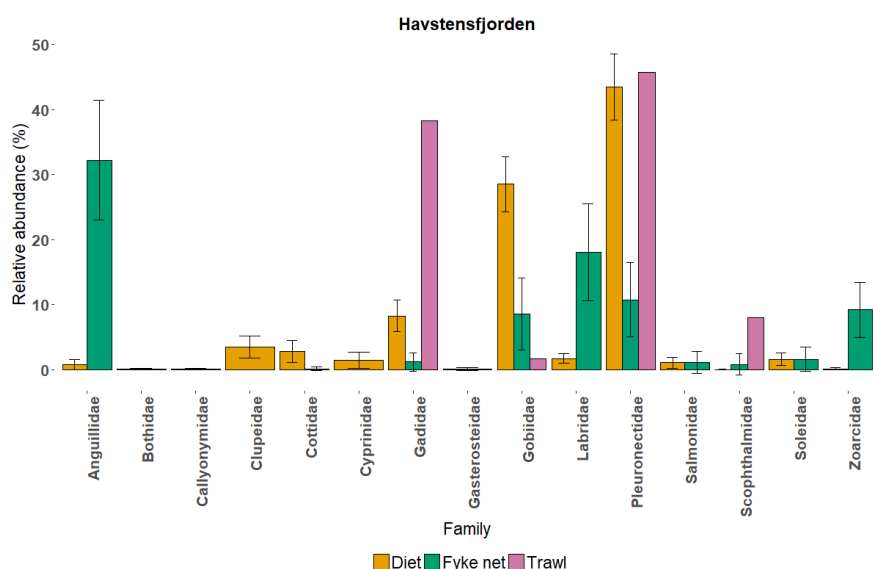


Figure 6. Diet composition in comparison to monitoring fishery data in Havstensfjorden. Relative abundance ( $\pm 95\%$  confidence intervals) of fish families in diet, fyke net survey from 2012 and trawl survey from 2016.

In Halse-Askeröfjorden, 9 families were found in the fyke net survey from 2012 whereas 6 families were found in the trawl survey from 2016. The most common families in the fyke net survey were codfish, eel (*Anguillidae*) and eelpout (*Zoarcidae*). The most common family in the trawl survey was codfish. In the diet, flatfish and gobies were the most common families (figure 7).

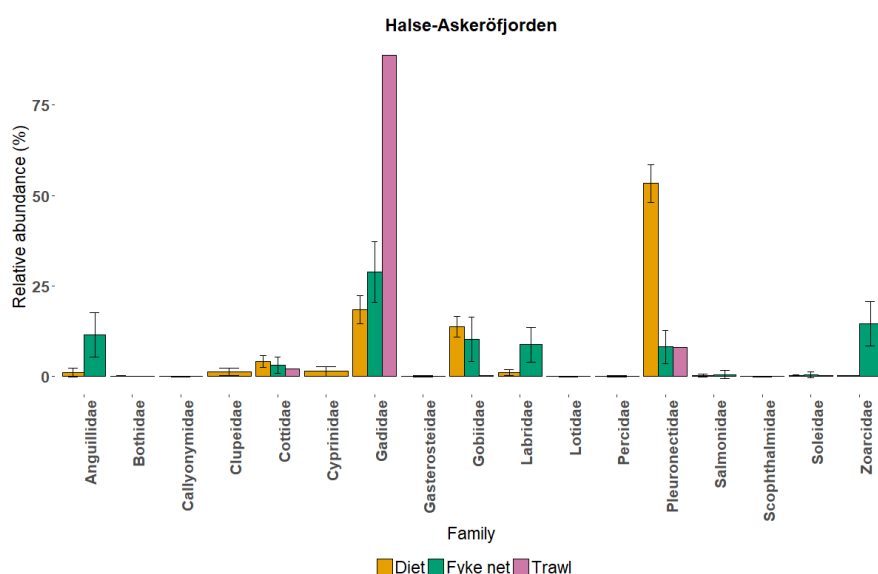


Figure 7. Diet composition in comparison to monitoring fishery data in Halse-Askeröfjorden. Relative abundance ( $\pm 95\%$  confidence intervals) of fish families in diet, fyke net survey from 2012 and trawl survey from 2016.

## Length distributions

Length distributions of estimated codfish sizes in the diet did not differ significantly between subareas (Wilcoxon rank sum test  $W=1979$ ,  $p=0.35$ ). The average estimated codfish size in the diet was 10.7 cm. In Halse-Askerøfjorden, the average codfish size was 16.4 cm in the fyke net survey and 14.5 cm in the trawl survey. Few codfishes were found in the surveys in Havstensfjorden, only 3 codfishes were found in the fyke net survey and 10 codfishes were found in the trawl survey. The average codfish size was 13.5 cm in the fyke net survey and 11.8 cm in the trawl survey (figure 8).

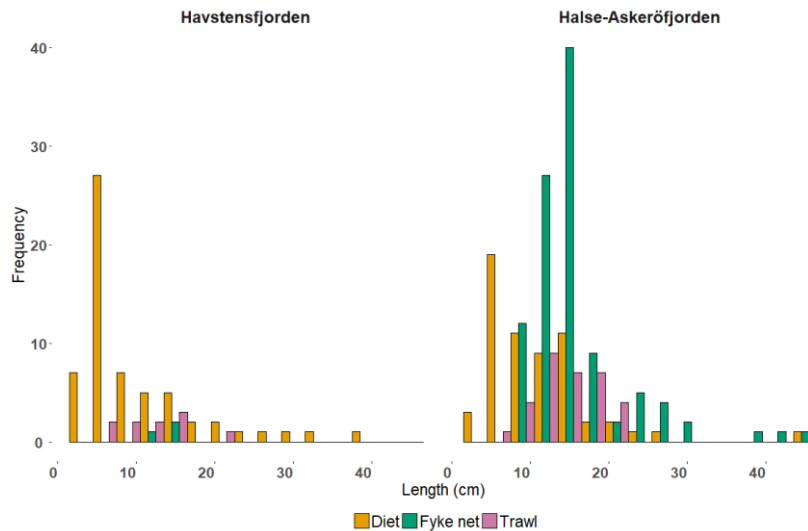


Figure 8. Length distributions of codfish. Comparison of fish lengths in diet and monitoring fishery data (fyke net survey from 2012 and trawl survey from 2016) in the two subareas.

Length distributions of estimated flatfish sizes in the diet did not differ significantly between subareas (Wilcoxon rank sum test  $W=1715$ ,  $p=0.65$ ). The average estimated flatfish size in the diet was 10.7 cm. In Havstensfjorden, the average flatfish size was 22 cm in the fyke net survey and 19.9 cm in the trawl survey. In Halse-Askerøfjorden, the average flatfish size was 18.5 cm in the fyke net survey and 16.2 cm in the trawl survey (figure 9).

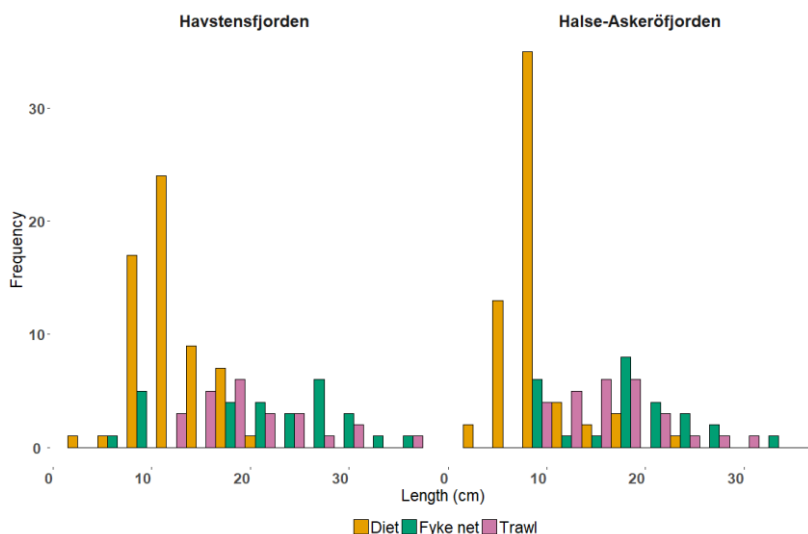


Figure 9. Length distributions of flatfish. Comparison of fish lengths in diet and monitoring fishery data (fyke net survey from 2012 and trawl survey from 2016) in the two subareas.

## Potential secondary consumption

Comparing the number of otoliths per family in pellets containing the piscivorous family codfish, with the number of otoliths per family in pellets not containing codfish, the occurrence of gobies was lower in pellets without codfish otoliths. A total of 243 pellet contained codfish, where 76% also contained gobies. In the 237 pellets not containing codfish, 51% contained gobies (figure 10).

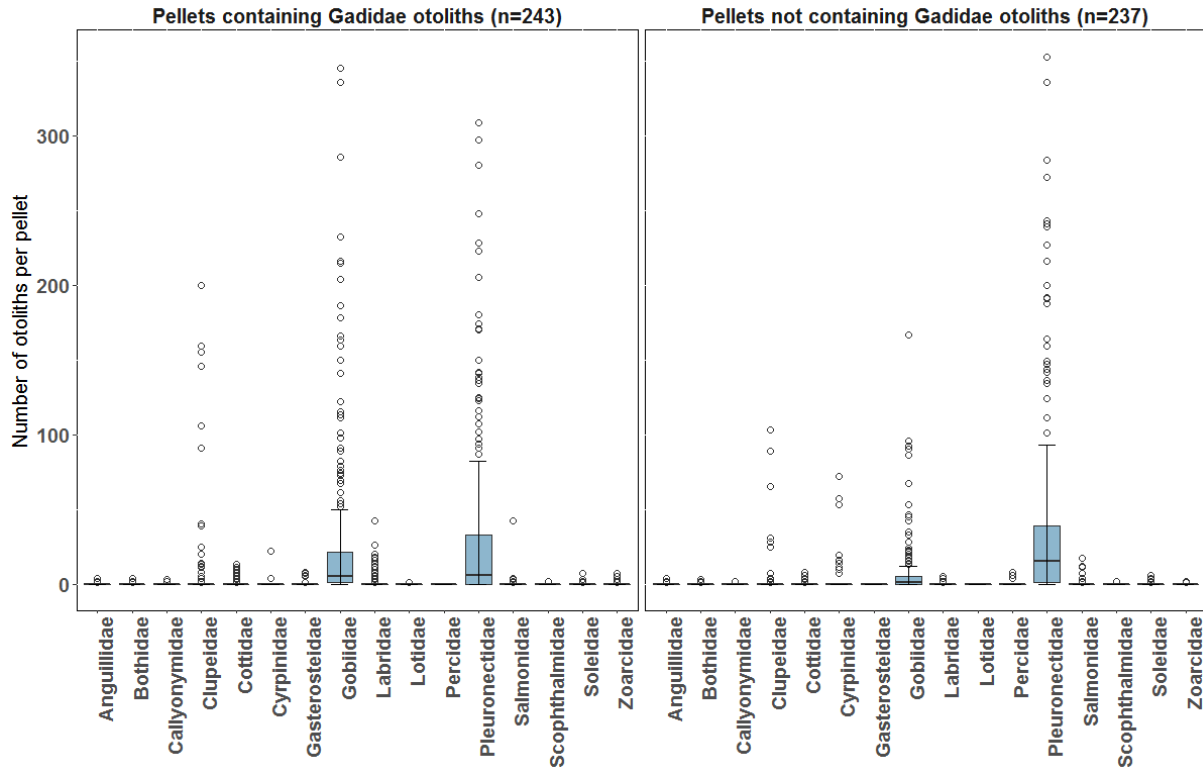


Figure 10. Boxplots showing number of otoliths per pellet and family in pellets with Gadidae otoliths (left) and in pellets without Gadidae otoliths (right). Plot shows 25th and 75th percentiles (boxes), median (line), 10th and 90th percentiles (whiskers) and outliers (dots).

## Discussion

In this study, cormorant prey choice in two subareas of the 8-fjords area was investigated. The most important families in the overall diet, based on relative abundance were flatfish (48%), gobies (21%) and codfish (13%). Due to morphological similarities between otoliths in combination with digestive erosion, species of flatfish and codfish were difficult to distinguish. From the flatfish family, plaice, flounder (*Plathichtys flesus*) and dab (*Limanda limanda*) were the most common species occurring in the area based on yearly trawl monitoring data and therefore, probable to occur in the diet. Only dab could be distinguished in the diet and comprised 31% of the total number of flatfish otoliths. From the codfish family, cod and whiting (*Merlangius merlangus*) were the most common species occurring in the area. Only whiting could be identified in the diet and comprised 7% of the total amount of codfish otoliths. However, the proportions of dab and whiting in their respective family could be underestimated due to difficulties in identifying the smallest otoliths to species level. The largest part of the goby otoliths (93%) were identified as black goby (*Gobius niger*). The remaining goby otoliths could not be species identified.

The restrictive fishing regulations in the 8-fjords area are implemented to protect the demersal fish stocks where cod, plaice and turbot are used as target species for the recovery. The results show that flatfish and codfish are important prey families in the cormorant diet. Turbot belongs to the Scophthalmidae family, which had a very low occurrence in the cormorant diet with a relative abundance of 0,03%. Therefore, turbot seems not to be an important prey of cormorants in the 8-fjords area.

The differences in diet composition between sites were extremely small, which suggests that cormorants prey on species of the same families to the same extent in both subareas. This result contrasts previous studies comparing cormorant diet between nearby areas (Lunneryd & Alexandersson 2005, Boström *et al.* 2012b). However, in contrast to the previous studies, this study was conducted during post-breeding season with a smaller distance between sampling sites, which could explain differences in the results. During breeding season cormorants commonly forage up to 15-20 km from the colony site, but move greater distances from roosting sites to forage during post-breeding season (Nelson 2005). This study assumes that cormorants feed within the subarea of their roosting site, however, the sites in the different subareas are located 20-25 km apart, which is within the movement range. Hence, it is possible that prey items in a pellet in one subarea originates from another subarea. The uncertainties in cormorant movement and feeding areas is stressed by the fact that two fresh water families were found in some of the pellets, whereas only marine species were found in the monitoring fishery surveys. Three pellets contained only fresh water species and 11 pellets contained both marine and fresh water species. The occurrence of both fresh water and marine species suggests that the cormorants have been fishing in both fresh water and marine waters during one day, or possibly in marine waters near a fresh water outlet. The lack of knowledge of cormorant movement pattern is further stressed by the inconsistency in their choice of roosting sites, as pellets were not found on each visit to the sites in Havstensfjorden.

## Diet in comparison to available monitoring fishery data

### Prey abundance

When comparing the diet to available monitoring fishery data, cormorant prey choice seems not to be related to prey availability. Predation on flatfish and gobies is high, even though the availability is low. In contrast, predation on codfish seems to be lower than the availability.

Additionally, the availability of eel, wrasses and eelpout were high in the fyke net survey, though rare in the diet.

The data from available monitoring fishery surveys in this area show large differences in prey availability. The differences in fish community composition between surveys could be the result of different inventory methods and year of inventory (trawling survey in 2016 and fyke net survey in 2012). Comparing the number of families, fewer families were found in the surveys (5 families in trawl survey and 10 families in fyke net survey) in comparison to diet (15 marine families). The trawling survey only captured one third of the marine species found in diet. A reason for this could be limited sampling effort, as the trawling survey was performed with one trawl haul per subarea and therefore, might not provide an accurate idea about the real fish community composition. Another reason could be the choice of feeding habitats for cormorants. Cormorants prefer to forage in shallow areas up to an average depth of 6 m, although they can forage up to a depth of around 30 m (Gremillet *et al.* 1999). The trawl survey was performed at depths of 15-21 m and the fyke nets were placed at depth up to 10 m. Hence, the species composition in fyke nets are more probable to resemble the cormorant diet composition. This can explain the better overlap with the fyke net survey which captured two thirds of the marine families found in diet.

Though the fyke net survey had a good overlap in the composition of fish families, the relative abundance of families differed a lot, which could be an effect of change in fish stock between 2012 and 2016. Fish stocks can vary between years and therefore, the fyke net survey from 2012 might not give an accurate indication of the fish community composition in 2016. The limitations of the available monitoring fishery data leaves uncertainties in the interpretation of cormorant prey choice in relation to prey availability.

### Length distribution

Fish size estimates of cod- and flatfish in the diet showed that cormorants seem to prefer juvenile fishes. In comparison to available monitoring fishery data, cormorants prey on fish of smaller sizes than what is mostly available. This apparent selection for juvenile fishes could be an effect of shallow feeding areas, where soft bottom shores serve as nurseries for juvenile fishes (Pihl & Wennhage 2002). Size-selective predation of cormorant on juvenile flatfish has previously been shown in Dutch and Danish coastal areas (Leopold *et al.* 1998, Nielsen *et al.* 2008), but whether this could affect recruitment rates is unknown. When comparing the length distributions, it is important to keep in mind that the size estimates are based on family regression equations of a subsample and should be interpreted as rough estimates.

### Potential secondary consumption

A potential bias in the data is the possibility of secondary consumption, where prey of prey is found in diet analysis. The number of possible secondary prey items can be reduced by investigating size ratios between piscivorous fish and supposed secondary prey within the same pellet (Oehm *et al.* 2016). For otoliths to appear in pellets as secondary prey items, they would have to be robust enough to be able to sustain the degree of erosion exposure from primary consumption until pellet analysis. Codfish are piscivorous predators, whose prey could potentially appear as secondary prey in cormorant pellets (Wennhage & Pihl 2002). Goby otoliths are robust and could potentially appear as secondary prey items. The large co-occurrence of codfish and gobies in the pellets might indicate that part of the gobies found in diet may be secondary consumption from codfish prey. The largest part of the goby otoliths was identified as black goby (*Gobius niger*), that inhabit vegetated soft bottoms (Widerholm 1987). Codfish species migrate to soft bottoms during night to feed (Pihl & Wennhage 2002) and black goby could thus be a common prey for codfish. The large co-occurrence could also be a result of prey availability for cormorants when foraging in vegetated soft bottoms,



however, cormorants are diurnal feeders and the availability of codfish in co-occurrence with black goby should thus be limited. Either way, the number of goby otoliths in many of the pellets containing codfish are considered too many to have been consumed by one or a few codfishes. Furthermore, the codfishes in each pellet would have to be large enough to consume a black goby large enough to appear in a pellet as secondary prey. Thus, the occurrence of black goby as secondary prey in cormorant diet is possible, though to a low extent. If measurements would have been made, the size of each codfish could have been estimated and potential secondary consumption could have been further investigated.

## Limitations of study method

Using pellets for morphological identification of prey remains is a beneficial method given that it allows frequent collection of samples and that it is a non-invasive technique that provides both quantitative and qualitative information about prey (Carss 1997, Barrett *et al.* 2007). However, the results of this method may be biased towards species with larger and more robust otoliths, as smaller and more fragile otoliths erode faster and are more difficult to find or identify (Duffy & Laurenson 1983, Casaux *et al.* 1995, Zijlstra & van Eerden 1995, Carss 1997). This bias can be corrected for by up-scaling species or families with small otoliths to give a more accurate idea about the relative abundance (Casaux *et al.* 1998). In this study, the lack of otolith measurements made the up-scaling unachievable. However, the generally small otolith sizes, lowered the otolith size difference between taxa which made a correction factor for small sized otoliths less important. Still, the relative abundance of families may, to some extent, be biased towards families with larger and more robust otoliths. Herring had the smallest otoliths of the taxa occurring in the diet and are likely to be underestimated here. It has previously been shown in an experimental study that herring otoliths has a low recovery rate in cormorant pellets (Johnstone *et al.* 1990). Hence, the relative abundance of taxa may be biased, although the bias should, to some extent, be evened out by small differences in otolith sizes between taxa.

## Future studies

Combining species identification with otolith measurements in pellet analysis can provide qualitative information about cormorant diet (Carss 1997, Barrett *et al.* 2007). Due to the difficulty in determining species in this study, the method has proven flawed as a sole method for investigating cormorant prey choice in the 8-fjords area. An alternative approach would be to combine pellet analysis with analysis of stomach contents from hunted birds. Though invasive, this method is better in the way that it can provide more detailed information about both species and sizes (Barrett *et al.* 2007), which pellet analysis failed to do in the 8-fjords area. Additionally, DNA-analysis of cormorant stomachs has been shown to find traces of small prey that is difficult to detect by morphological analysis (Oehm *et al.* 2016).

This study has provided information about cormorant prey choice in the 8-fjords area during post-breeding season (September-October). Cormorant diet may vary between seasons and therefore a continuous data collection is necessary to detect differences in diet with changes in fish community composition and cormorant life stages (Boström *et al.* 2012a, Lehikoinen 2005, Emmrich & Düttmann 2011). Another important factor is to monitor the movement pattern of cormorants. Today, there is no knowledge about how far they move from their roosting sites and where they feed, which is crucial information for estimating the impact on local fish stocks. Moreover, in addition to cormorant movement patterns, information about cormorant census in the area is lacking and inventories are needed during all seasons. Finally, to be able to estimate potential impact of cormorant predation on demersal fish stock, more reliable monitoring fishery data is necessary.

## Conclusions

This study has shown that the protected species in the 8-fjords area belong to the most important prey families in the cormorant diet. Whether this could be an effect of prey availability is uncertain based on available monitoring fishery data. High predation still suggests a high availability of flatfish, gobies and codfish during post-breeding season, although more information about prey species and cormorant foraging areas are needed. Future studies on cormorant prey choice in the 8-fjords area would benefit from combining pellet analyses with other dietary methods, such as analysing cormorant stomachs and DNA-based diet analysis to obtain high-quality information about prey.

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