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Abstract

The Swedish population of great cormorant (*Phalacrocorax carbo sinensis*) has rapidly increased to over 40 000 breeding couples since the EU-protection 1980. Since the cormorant are high efficient predators living in large colonies, they are accused for reducing fish populations and competing with fishery. An intense conflict between cormorants, fishery and conservationist has arisen. Cormorants are top predators in the food web. It is therefore essential to attain knowledge regarding their ecological role and fish consumption, to be able to evaluate the effects on the ecosystem, but also to evaluate the competition between cormorants and fishery. This study aims to assess the prey species composition of cormorants on Gotland based on otoliths from regurgitated pellets. 397 pellets were collected and analysed from four different localities, divided into north and south. The pellets together contained 4363 otoliths which were identified to the lowest possible taxon. To correct for biases caused by eroded otoliths, and complete loss of otoliths, size correction factors (SCF) and numerical correction factors (NCF) were applied. Results shows that cod (*Gadus morhua*), European flounder (*Platichthys flesus*) and sticklebacks (*Gasterosteidae*) dominated the diet in the north area, while shorthorned sculpin (*Myoxocephalus scorpius*), cod and European flounder dominated in the south. The results contribute with valuable information regarding cormorant diet in the Baltic sea. This information increases the understanding how cormorants can affect fish populations and identify possible management measures. To fully evaluate the effects of cormorants on fish populations, ecosystem and fishery, additional studies are necessary.

Keywords: Baltic sea, regurgitated pellets, otoliths, prey species composition, sea birds

1. Introduction

Human-wildlife conflicts occur when an action, either by humans or wildlife, has negative impacts upon other (Conover, 2002). Birds and fisheries have a diverse range of conflicts worldwide, where the conflict between fish-eating cormorants (*Phalacrocorax* spp.) and fisheries is perhaps the most widespread (Doucette *et al.*, 2011; Tasker *et al.*, 2000). Human-wildlife conflict can also be a conflict between humans over wildlife, were social factors can be of higher importance than the actual wildlife damages (Dickman, 2010). These sort of conflicts are complex and covers a wide range of factors such as biological, economic, social, and cultural issues (Young *et al.*, 2010). The cormorant conflict is complex and involves different stakeholders. Conservationists see the return of cormorants as a story of success, while fishermen perceive cormorant return as a cause of reduced catches.

The great cormorant (*Phalacrocorax carbo*) occurs in two subspecies in Europe; *P. c. carbo* and *P. c. sinensis.* The former is restricted to the Atlantic coast of Norway, Britain, Ireland and northern France, while *P. c. sinensis* breed in continental Europe and Scandinavia (Gagliardi *et al.*, 2015; Cramp, 1980). In this thesis, “cormorant” is referring to the *P. c. sinensis*, if nothing else is stated. These birds were long kept at low numbers in most of Europe due to persecution, land reclamation and disturbance (Marzano & Carss, 2012; Engströn, 2001a; Lindell *et al.*, 1995; Vaneerden & Gregersen, 1995). In 1965 and 1977 the species became protected in the Netherlands and Denmark respectively, followed by protection in the EU from the EC Birds Directive (Directive 79/409/EEC) in 1980. This is perceived to be the main reason behind the exponential population growth. However, also an increased fish productivity in European water due to eutrophication is thought to be a contributing factor (Marzano & Carss, 2012; Denie, 1995; Vaneerden & Gregersen, 1995; Vaneerden *et al.*, 1995). The population spread and increased, correspondingly did the conflict in a variety of habitats across Europe such as rivers, lakes, freshwater aquaculture ponds, coasts, and costal aquaculture sites (Klenke *et al.*, 2013; van Eerden *et al.*, 2012; Carss, 2003; Moerbeek *et al.*, 1987).

In 1997 the cormorant was removed from Annex 1 in the directive of Conservation of Wild Birds since it had reached favourable conservation status. This meant that it is now possible for EU member states to manage cormorants under condition stated in Article 9 (Directive 2009/147/EC). Article 9 can be used if: (1) It is in the interest of public health and safety, (2) air safety, (3) to prevent serious damage to crops, livestock, forest, fisheries and water, (4) for the protection of flora and fauna. It is up to member states to decide on how much evidence is needed to prove the cormorant predation effect, before measures can be implemented. Fish population/communities are regulated/controlled by many biotic and abiotic factors, of which bird predation is but one. Evaluating cormorants effect on fish populations, in relation to other biotic/abiotic factors is therefore difficult (Cowx, 2013; Marzano *et al.*, 2013; Östman *et al.*, 2012; Cramp, 1980).

1.2 The cormorant in Sweden

The cormorant population in Sweden followed the same pattern as in the rest of Europe. It first disappeared due to persecution in the end of the 19th century, but re-established in the late 1940s south of Kalmar (Lindell *et al.*, 1995). Bird numbers remained low in Sweden until the 1980s. Thereafter the population increased rapidly from 753 breeding couples in 1980 to 40 598 in 2012, which makes Sweden the country in the Baltic Sea area that holds the highest number of breeding couples (Herrmann *et al.*, 2014). This vast population growth has also led to a renewed conflict in the Baltic Sea area, including Sweden (Östman *et al.*, 2013; Eschbaum *et al.*, 2003; Engström, 2001a). Fishery and cormorants in the Baltic sea can compete over shared fish resources and Swedish commercial fishermen perceive cormorants as a problem mainly due to consumption and injuries to fish in fishing gear (Östman *et al.*, 2013; Eschbaum *et al.*, 2003; Engström, 1998; Lindell, 1997). Fishermen also claim that large colonies of cormorants consume large quantities of fish, which can lead to reduction in fish stocks and reduce catches of economically important species (Engström, 1998).

The population increase seems to, not only have stagnated, but also experienced a slight decline in Sweden (Herrmann *et al.*, 2014). 82 % of the Swedish population breed along the coastline (Naturvårdsverket, 2013). North of the Åland Sea the colonies are sparse. The south coast area of the Baltic Sea, holds the highest numbers of breeding pairs (Engström, 2001b). Gotland, situated in the Baltic Sea, holds approximately 20 % of the Swedish population (Naturvårdsverket, 2013). This is the county in Sweden with the highest numbers of breeding couples. However, the first breeding couple on Gotland did not occur until 1992 (Herrmann *et al.*, 2014). Thereafter the population increased rapidly until 2008 when more than 10 000 couples inhabited Gotland. After the peak year in 2008, the population seem to have stagnated between 8-10 000 from 2009 until 2016 (Kjell Larsson, pers. comm, 2017). Between the commercial fishery and the recreational fishery, it is the recreational fishery that are stating problems connected to the cormorant (Rolf Gydemo, pers. comm, 2017). The two most important species for commercial fishery are herring (*Clupea harengus*) and European sprat (*Sprattus sprattus*), while the most important species for recreational fishery are trout (*Salmo trutta*), perch (*Perca fluviatilis*), European whitefish (*Coregonus lavaretus*) and northern pike (*Esox lucius*). Also European flounder (*Platichthys flesus*), cod (*Gadus morhua*) and turbot (*Scophthalmus maximus*) are species of importance for household fishing.

1.3 The cormorant – species description

The cormorant (*Phalacrocorax carbo*) have a global distribution and are considered an avian top-predator (Klimaszyk & Rzymski, 2016; Cramp, 1980). They breed close to both salt and fresh water. Proximity to water is an absolute requirement since it is a diving sea-bird which mainly feed upon bottom-dwelling fish species, (Causey & Padula, 2014; Johnsgard, 1993). The cormorant almost exclusively feeds on fish, and is also an extremely effective predator (Gremillet *et al.*, 2004; Gremillet *et al.*, 1999). Cormorants are both generalists and opportunist, meaning that they possess a high adaptability to the prey available (Gremillet, 1997; Gremillet *et al.*, 1995). There is a wide range of estimations on cormorants daily food intake (DFI); 539 g/day (Keller & Visser, 1999), 146-699 g/day, highest in October and March (Dirksen *et al.*, 1995), 238-588 g/day, lowest when incubating and highest when rearing downy chicks (Gremillet *et al.*, 1995) and 800-890 g/day including fish brought to chicks (Gremillet *et al.*, 1996). However, in a review by Ridgway (2010), a number of DFI-estimations based on different methods was summarized. He concluded that the average DFI during nesting season were 542 g/day, and 436g/day in the non-nesting season. The cormorant breeds in colonies of a few couples up to 8 000-10 000 (Naturvårdsverket, 2013; Vaneerden & Gregersen, 1995). Nesting and nest construction can vary greatly but they are known to breed on level ground, cliffs, bridge supports, wharfs and in trees. According to SOF (2013) the largest colony in Sweden consists of 1984 pairs and is found on Gotland. The breeding season in the south of Sweden occurs in April-June, the incubation period lasts for nearly a month and after 43-55 days the chicks can leave the nests, but the parents look after them for another eight weeks (Naturvårdsverket, 2013; Rahimi *et al.*, 2012; Johnsgard, 1993). Roosts are of two kind, either diurnal or nocturnal (Cramp, 1980). Diurnal roosts in feeding areas is used for resting and digesting meals, before flying to nocturnal roosts often located on small island. During late summer/autumn, a high number of cormorants leave Sweden for overwinter areas in continental Europe and north Africa (Fransson & Petterson, 2001). Some also stay in the south of Sweden during the winter (Naturvårdsverket, 2013). The migrating birds return in February-April.

1.4 The use of pellets in diet studies

Diet studies is central to understand seabird's adaptations to the marine environment (Barrett *et al.*, 2007). There are different methods used to investigate the diet of sea birds; (1) direct observation of feeding birds, (2) examining stomach contents of dead birds, (3) examining regurgitated fish from colonies during breeding season, (4) analyse remaining hard part from regurgitated pellets (Boström, 2013; Carss *et al.*, 1997; Johnstone *et al.*, 1990). All methods listed have their limitations. Since this thesis covers pellet analysis, limitations connected to this method will be described below. Information of limitations for the remaining methods, see (Boström, 2013; Barrett *et al.*, 2007; Carss *et al.*, 1997; Zijlstra & Vaneerden, 1995). The use of pellets involves little effort and low disturbance to the birds, and during non-breeding season this may be the only available alternative to collect information about the diet.

Cormorants swallow their prey whole and regurgitated mucus coated pellets are produced once a day, containing the indigestible prey remains, such as the ear stones (otoliths) (Naturvårdsverket, 2003; Zijlstra & Vaneerden, 1995; Duffy & Laurenson, 1983). Teleost fish holds three pairs of ear stones (otoliths). The largest pair is called sagittae and is the most commonly used in studies (Campana & Neilson, 1985). Sagittae otoliths are species-specific, and therefore often used in taxonomy (Härkönen, 1986). It is also possible to estimate fish size based on otolith size by using regression lines between otolith size and fish size (Leopold *et al.*, 2001; Härkönen, 1986). Pellets has been used extensively to obtain information about diet of cormorants and shags (*Phalacrocorax spp.*) (Leopold *et al.*, 1998; Keller, 1995; Montevecchi *et al.*, 1990; Duffy & Laurenson, 1983). However, this method has been criticized to produce a bias in fish size and fish numbers (Tollit *et al.*, 1997; Suter & Morel, 1996; Zijlstra & Vaneerden, 1995; Johnstone *et al.*, 1990; Duffy & Laurenson, 1983). This, since otoliths from pellets are eroded by gastric acids and become smaller than original size, leading to an underestimation of fish size when applied to regression lines. Complete loss of otoliths, due to erosion, also occurs. Fish species with smaller otoliths show lower recovery rate in pellets. Daily food intake of cormorants should therefore not be based on pellet analysis (Carss *et al.*, 1997). Pellet analysis is however a relatively easy data collection method, and sometimes the only available during non-breeding season when pellets can be collected at roosts (Carss *et al.*, 1997; Zijlstra & Vaneerden, 1995). It is also a useful method to investigate in spatial and temporal variation (Carss *et al.*, 1997).

1.5 Earlier studies in the Baltic Sea area

In Finland two different studies analysed regurgitated fish collected from colonies during breeding season (Lehikoinen *et al.*, 2011; Lehikoinen, 2005). Common prey species were roach (*Rutilus rutilus*), eelpout (*Zoarces viviparus*) and perch. In the western Baltic Sea, in Sweden, 229 cormorants were shot and stomachs content analysed (Boström *et al.*, 2012b). Sticklebacks (*Gasterosteus aculeatus* and *Pungitius pungitius*) were most common, but also eelpout, herring and cyprinids (Cyprinidae) proved to be of significant importance. Östman *et al.*, (2013) used the same method and concluded that cormorant may locally have a direct impact on human catches of flounder, but also indirect effect on perch and pike. Research conducted indicate that perch may be an important prey species when abundant, and also the most vulnerable species to cormorant predation (Östman *et al.*, 2012; Vetemaa *et al.*, 2010; Lehikoinen, 2005). As far as I know, only one diet study (Hjernquist, 2008) has been conducted on Gotland before 2017. This long term study was conducted between 1992-2016 on the island Lilla Karlsö on the west coast of Gotland. Based on regurgitated fish from chicks during breeding season, stickleback and eelpout showed to contribute to around 90 % of the prey biomass.

In 2006 a large fishing free area, was established on the north of Gotland (Florin *et al.*, 2013). The study evaluated how the absence of fishery effected flatfish populations. Cormorant predation was calculated and taken into account. They were shown to be potential important predators. Calculations however, were based on cormorant diet data from the west-coast of Sweden since diet studies from Gotland is lacking. The authors ask for better information on cormorant prey choice on Gotland to fully separate these predators from other mortality factors.

1.6 Aim with the study

Cormorants are top predators in the food web. It is therefore essential to attain knowledge regarding their ecological role and fish consumption, both to be able to evaluate the effects on the ecosystem, and to evaluate the competition between cormorants and human fisheries. This knowledge is of importance for the local professional fishing, recreational fishing and sport fishing tourism. Additional, cormorants can indicate changes in the Baltic sea ecosystem. Variation in their occurrence and prey preference can be interpreted as changes in the ecosystem. To fully evaluate the ecosystem effects, and to what extent cormorants compete with fishery, further studies are needed. But this is a first step to increase the knowledge around cormorant's diet on Gotland. How the cormorant effect fish populations are important to understand, if we are to maintain sustainable fish population and fishery.

This thesis investigates the post-breeding diet of cormorants on Gotland. The aim is to assess the variation in food composition based on otoliths from regurgitated pellets. The results will reveal the prey species composition on the north and south of Gotland. Prey species composition will be presented as frequency of occurrence, numerical contribution, and biomass contribution. The result can be used in future studies, investigating cormorant diets changes on Gotland. In addition, the project will produce objective information on the food choice of cormorants on Gotland. The results will contribute to valuable knowledge to the sometimes infected debates related to cormorants.

2. Material and methods

2.1 Study area & pellet sampling

Regurgitated pellets were collected on four different locations on Gotland between 16 September and 10 November in 2016 (*figure 1*). Pellets were collected on roost sites after breeding season. Two locations were situated approximately 4.5 km apart, on the northeast of Gotland; Furillen (N57.759156, E19.001967) and Smöjen (N57.730046, E18.956652). These two location are pooled in the results section, and are hereafter referred to as “north area”. At both these locations pellets were collected at old harbours with concrete piers. The other two locations were situated approximately 18.5 km apart, on the southeast of Gotland; Storholmen (N57.278638, E18.743520) and Ronehamn (N57.171037, E18.492433). These two location are pooled in the results section, and are hereafter referred to as “south area”. At Storholmen, pellets were collected on a dock. In Ronehamn, pellets were collected on a lighthouse and in the harbour.

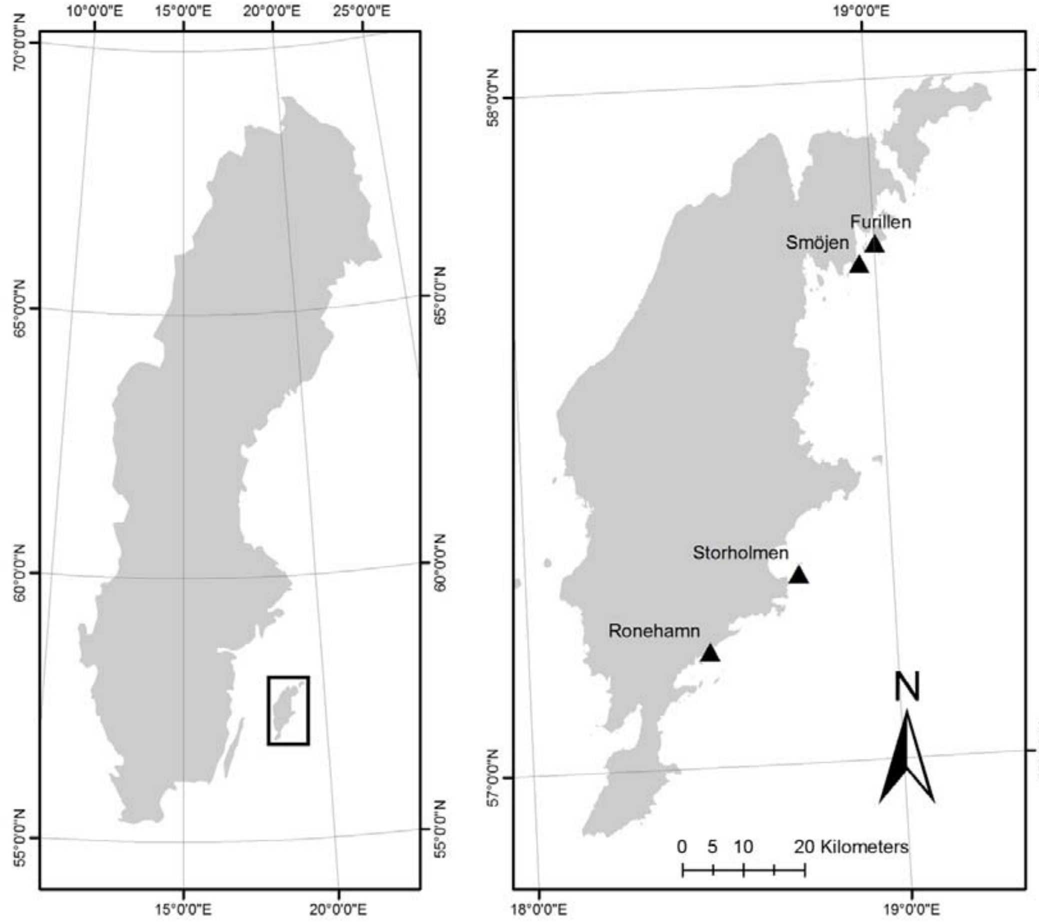

Figure 1. Maps over Sweden and Gotland showing the four locations where pellets were collected between 16 September and 10 November in 2016. The north area (Furillen and Smöjen) and the south area (Storholmen and Ronehamn).

Collection occurred four times at each location, with approximately two weeks apart. At each occasion all intact and fresh pellets found were collected. Pellets were stored in a freezer to limit erosion until analysis. Cormorants are believed to eject pellets at dawn, containing fish remains eaten the day before (Zijlstra & Vaneerden, 1995), therefore pellet collection mainly occurred in the morning to avoid pellets being eaten by gulls and crows.

Pellets from each sampling occasion were randomly sampled from the freezer if $n>20$. If $n\leq 20$ all pellets were analysed. If pellets showed to be empty, new pellets were randomly sampled (if possible) until 20 pellets with prey remains from each were achieved. Before sorting out otoliths and hard parts, pellets were first dissolved in small plastic jars filled with water for a couple of days. This procedure is important since the smallest otoliths often are found in small pockets of mucus, and can therefore often be missed if not dissolved (Härkönen, 1986). When dissolved, pellets were washed out and all otoliths and other hard parts were extracted and dried. Otoliths were identified to the lowest possible taxon according to (Leopold *et al.*, 2001; Härkönen, 1986). Sticklebacks (*Gasterosteidae*) were identified by fin spines. Due to erosion, some otoliths could only be classified into family. Highly eroded otoliths were not possible to identify, these were classified as “unknown”. All otoliths were measured by width (OW) with a digital loup, except “unknown” which only were assigned a wear class. If other hard remains could be classified to species or family, fish size estimation were calculated as the mean size from that species. Since each fish has two sagittae otoliths, the number of otoliths in each pellet were divided by two to attain the number of individuals.

2.2 Fish size estimations

To estimate fish size, species-specific regressions slopes obtained from Leopold *et al.*, (2001) was used to back-calculate fish weight from otoliths, except for gobies (Gobiidae) were the regression slope from Härkönen (1986) were used. For otoliths only classified to family; gobies, sand lance *(*Ammodytidae*)* and cyprinids, regression slopes for black goby (*G. niger*), sandeel and roach respectively, were used. If otoliths were wider or thinner than otoliths used to produce the regressions slopes in Leopold *et al.*, (2001) and Härkönen (1986), otoliths were downgraded or upgraded to the largest or smallest otolith from the regression slope. The reason for this was to avoid overestimations and underestimations of fish size. Unknown otoliths were excluded in the fish size estimations. Since sticklebacks were identified by fin spines, fish size estimation was not possible. Sticklebacks were assumed to be three-spined stickleback (*Gasterosteus aculeatus*), and therefore given the weight of 2 gram (Jurvelius *et al.*, 1996). The number of sticklebacks in each pellet were calculated as the number of spines divided by five (the number of spines on each stickleback).

One method used to compensate fish size underestimation, due to erosion of otoliths, is to use size-correction factors (SCF). This method has been used in diet studies of both marine mammals and cormorants (Boström *et al.*, 2012a; Boström *et al.*, 2012b; Lundström *et al.*, 2007; Lunneryd & Alexandersson, 2005; Leopold *et al.*, 1998). To calculate SCF in this study, each otolith were assigned one of the three wear class according to Tollit *et al.* (1997). Class 1 showed minimum erosion with well-defined surface, margins, sulcus and rostrums. Class 2 were affected by erosion showing less distinct characteristics, together with more rounded rostrums and edges. Class 3 were highly eroded and showed an altered shape, no sulcus and smooth edges. Reference material, used for classifying otolith wear class, were found in Härkönen (1986) and Leopold *et al.*, (2001). Otoliths assigned wear class 1 for each species, are considered to be the original size of the otoliths. SCF for class 2 and 3 are simple the average width of each species class 1 otoliths, divided by the average width of the same species class 2 and 3 respectively. In this study however, too few otoliths were assigned class 1, making it impossible to calculate correction factors. Therefore, class 1 and 2 were pooled and SCF were only calculated for class 3. Wear class 1 and 2 are hereafter referred to as "class 1+2" and class 3 as "class 3". SCF were estimated for the four most abundant species in the study. For the other species, average SCF from those four species were used. SCF-values for species *x* were multiplied to all otoliths from species *x* of class 3 in the dataset. Unknown otoliths were not assigned a SCF.

2.3 Fish consumption

To describe the contribution of each species in the cormorant diet, three different indicators were used. The north area and south area were treated separately. Frequency of occurrence (FO_i) for each species was calculated as the number of pellets containing the species, in relation to the total number of pellets containing remains of prey. Relative numerical contribution (N_i) for each species was calculated as the number of individuals of each species, in relation to the total number of individuals of all species, in each pellet. Relative biomass contribution (B_i), were calculated as the total biomass from each species, in relation to the total biomass of all species, in each pellet. For all these indicators, unknown otoliths and empty pellets were excluded in the analysis.

To compensate for complete loss of otoliths numerical contribution factors (NCF) were used. This method has earlier been used in seal diet studies (Lundström *et al.*, 2007; Tollit *et al.*, 2007; Tollit *et al.*, 1997). NCF from cormorant diet is more scarce, but has been estimated based on differences between stomach contents and pellets (Casaux *et al.*, 1998). In this study, data from captive feeding trails on cormorants were used (*table 1*) (Martucci *et al.*, 1993; Johnstone *et al.*, 1990). Based on the fish size fed to cormorant, otolith width (OW) was calculated using regression slopes from Leopold *et al.*, (2001). In the study of Martucci *et al.*, (1993), OW were given and no calculation were needed. The otolith recovery rate (RR) for each species were given in the studies and NCF were calculated from RR (equation 2).

Table 1. Average fish length (FL) and RR for Sandeel, Herring, Sprat and Cod from Johnstone et al., (1990). Otoliths width (OW) were calculated using regression slopes between FL and OW from Leopold et al., (2001). For Sandsmelt (Atherina boyeri), Striped mullet (Mugil cephalus), Sole (Solea solea) and Eel (Anguilla anguilla) OW and RR were recovered from Martucci et al., (1993).

Common name	**Species**	**FL (mm)**	**OW**	**RR**
Sandeel	*A. marinus*	157	1.37	0.32
Herring	*C. harengus*	134	1.27	0.22
Sprat	*S. sprattus*	165	1.50	0.22
Cod	*G. morhua*	188	3.10	0.73
Sandsmelt	*A. boyeri*	-	2.45	0.13
Striped mullet	*M. cephalus*	-	3.42	0.84
Sole	*S. solea*	-	3.05	0.83
Eel	*A. anguilla*	-	1.57	0.00

The NCF-values were then applied to dataset by multiplying the NCF-values for taxon *x* to species *x* in each pellet.

2.3 Confidence intervals

Each pellets were treated as one sample. The proportion of each species contribution to each pellet, were converted into % (except for frequency, were a species occurrence were registered as 1). From the dataset of *n* pellets from each area, *n* pellets were randomly sampled with replacement and an average is calculated from the *n* pellets. This process was then repeated 1000 times, generating 1000 estimates. This is a bootstrap technique from which confidence limits for FO_i, N_i and B_i were calculated based on the bias-corrected percentiles described in Haddon (2001). Bootstrapping has been widely used in animal diet studies, e.g. (Van de Ven *et al.*, 2013; Lundström *et al.*, 2007; Santos *et al.*, 2001). Bootstrapping allows to derive error estimates without making any assumptions about the data distribution (Santos *et al.*, 2001). The calculations were computed in the statistical program SPSS.

3. Results

3.1 Pellet analysis

In total 639 pellets were collected of which 397 were analysed (*table 2*). Out of these 397 pellets, 138 (35 %) were empty and 259 contained prey remains. In these 259 pellets, 4363 otoliths were found from 10 different families. 22 % of the otoliths were left unknown.

Table 2. Pellet collection based on four sampling occasions at each location. Collection occurred between 16 September and 10 of November in 2016 at Furillen, Smöjen, Storholmen and Ronehamn. Total number of pellets collected, analysed, containing remains of fishes, and empty from each location are shown.

	North area			**South area**			**Total**
	Furillen	**Smöjen**	**Total**	**Storholmen**	**Ronehamn**	**Total**	
Pellets							
Collected	280	130	*410*	153	76	*229*	639
Analysed	178	59	*237*	84	76	*160*	397
Remains	71	51	*122*	78	59	*137*	259
Empty	107	8	*115*	6	17	*23*	138
Otoliths							
Total	2078	944	*3022*	806	535	*1341*	4363
Unknown	433	215	*648*	223	106	*329*	977

3.2 Fish size - SCF

SCF were calculated for cod, shorthorned sculpin (*Myoxocephalus scorpius*), European flounder and gobies (*table 3*). The average for these four species (1.17), were used as SCF for the remaining species within the wear class 3.

Table 3. Prey species in this study and wear-class specific size-correction factors (SCF). Average SCF were used for remaining species in the data-set. SCF for erosion class 3 were calculated from the average otolith width (OW) in the two classes 1+2 and 3.

	Average OW		**SCF**	
Species	**1+2**	**3**	**1+2**	**3**
Cod	4.79	3.79	1	1.26
Shorthorned sculpin	2.25	1.79	1	1.26
European flounder	2.73	2.42	1	1.13
Gobies	1.92	1.86	1	1.03
Average			1	1.17

3.3 Fish consumption

Based on the data from the captive feeding trails (*table 1*), a linear regression between OW and RR was constructed (*equation 1, figure 2*). The RR for each species in this thesis were calculated from equation 1, where x = average OW from each species. Smaller otoliths showed lower RR than larger (*table 4*).

$$RR = 0.3158x - 0.2891 \qquad (1)$$

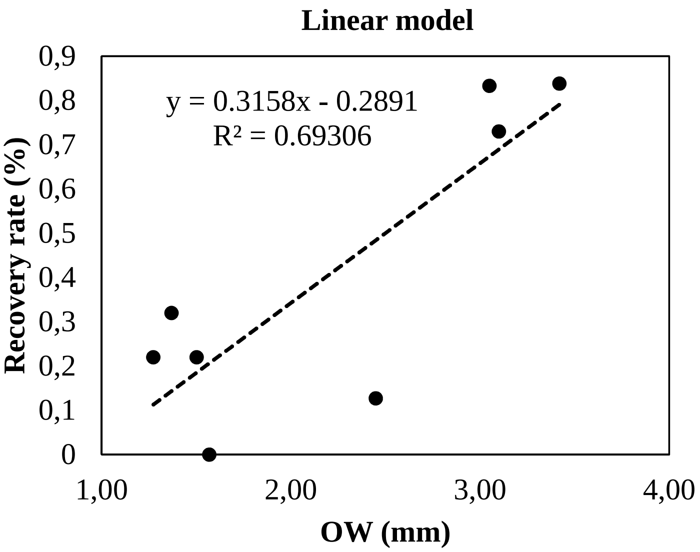

Figure 2. Regression model where recovery rate (RR) of different species is dependent on the otolith width (OW).

For each species NCF were calculated from the RR using equation 2. Sticklebacks were identified by fine spines, therefore NCF could be calculated. Unknown otoliths were not assigned a NCF.

$$NCF = \frac{1}{RR} \qquad (2)$$

NCF for cod were calculated to 0.85. Values <1 is not possible, therefore RR = 1 were used for cod. NCF values varied between 1 (cod) and 12.44 (eelpout).

*Table 4. NCF calculated from the average OW from species in this study using the linear model from figure 1. *NCF = 1 were used*

Common name	**Species**	**OW**	**RR**	**NCF**
Sand lance	Ammodytidae	1.32	0.13	7.83
Turbot	*S. maximus*	1.97	0.33	3.00
Herring	*C. harengus*	1.44	0.17	6.04
Shorthorn sculpin	*M. scorpius*	2.25	0.42	2.37
Cyprinids	Cyprinidae	2.58	0.53	1.90
Cod	*G. morhua*	4.76	1.21	0.82*
Gobies	Gobiidae	1.75	0.29	3.42
European flounder	*P. flesus*	2.68	0.56	1.79
Eelpout	*Z. viviparus*	1.17	0.08	12.44

3.4 Prey species composition

In the north area the highest number (No) of otoliths found belonged to gobies (*table 5*). The majority of the species occurred (FO%) in 19- 41 % of the pellets, with exception for turbot, herring, shorthorned sculpin and cyprinids which occurred in < 8 %, of the pellets. Gobies was also the species that occurred most often (41%) and showed highest numerical contribution (Ni %) of 27 %. However, the biomass (Bi %) from cod were the highest (26%), together with European flounder (20 %) and sticklebacks (19%).

In the south area the highest number of otoliths found belonged to shorthorned sculpins (*table 5*). Shorthorned sculpin, European flounder, cod and gobies occurred in 29- 62 % of the pellets. The rest occurred in < 9 %, of the pellets. Shorthorned sculpins was the species that occurred most often (43%), showed highest numerical contribution (27 %), and also contributed to the highest amount of biomass (40 %). Cod (27%) and European flounder (22%) also showed high biomass contribution.

Table 5. Fish consumption from the north and south area based on 115 and 131 pellets respectively. The total number of individuals from each species (No) are shown without the NCF. Frequency of occurrence (FO%), numerical contribution (Ni%) and biomass contribution (Bi%) are shown with a 95 % confidence interval (Cl).

North area

Species	**No**	**FO %**	**Cl**	**Ni %**	**Cl**	**Bi %**	**Cl**
Ammodytidae	29	19.13	13.04 - 26.09	5.33	2.74 - 8.23	3.40	1.52 – 5.70
S. maximus	1	0.01	0.00 - 1.74	0.00	0.00 - 0.00	0.01	0.00 - 1.95
C. harengus	12	7.83	2.61 - 13.04	2.52	0.77 - 5.04	3.05	0.88 - 5.70
M. scorpius	10	6.96	1.74 -13.04	4.01	1.38 - 7.24	2.77	0.74 - 5.57
Cyprinidae	1	0.01	0.00 - 1.74	0.01	0.00 - 1.14	0.00	0.00 - 0.02
G. morhua	59	35.65	26.09 - 45.22	13.02	8.33 - 18.32	26.39	19.42 - 33.55
Gasterosteidae	16	27.83	20.00 - 35.65	20.63	13.59 - 28.24	19.28	13.33 - 25.87
Gobiidae	419	41.74	32.62 - 50.86	27.43	20.75 - 34.32	14.12	9.37 - 19.48
P. flesus	72	31.30	23.48 - 39.13	16.60	11.63 - 21.79	19.84	12.95 - 26.99
Z. viviparus	50	20.00	13.04 - 27.37	9.84	5.54 - 14.24	10.65	6.43 - 15.48

South area

Species	**No**	**FO %**	**Cl**	**Ni %**	**Cl**	**Bi %**	**Cl**
Ammodytidae	9	5.34	1.53 - 9.92	2.04	0.66 - 3.77	0.01	0.13 - 1.46
S. maximus	3	0.01	0.00 - 1.53	0.00	0.00 - 0.09	0.00	0.00 - 0.14
C. harengus	16	8.40	4.58 - 13.50	4.85	2.36 - 7.68	3.24	1.04 - 6.07
M. scorpius	231	61.83	52.67 - 70.99	43.33	36.55 - 50.10	40.20	32.79 - 47.63
Cyprinidae	1	0.01	0.00 - 1.53	0.00	0.00 - 0.53	0.00	0.00 - 0.78
G. morhua	59	37.40	29.77 - 45.04	14.30	9.95 - 19.11	26.51	20.47 - 33.43
Gasterosteidae	4	6.11	3.05 - 9.92	3.47	1.10 - 6.18	3.22	0.77 - 6.11
Gobiidae	28	29.01	22.90 - 35.11	10.17	7.01 - 13.84	1.97	0.53 - 3.91
P. flesus	124	38.93	30.53 - 47.33	19.72	14.64 - 25.40	21.84	16.00 - 27.78
Z. viviparus	11	3.82	1.53 - 6.11	1.97	0.42 - 3.77	1.84	0.40 - 3.66

4. Discussion

4.1 Results – species composition

When comparing south and north, the south area is dominated by three species. Shorthorned sculpin, cod and European flounder together contributed to 89% of the biomass (*table 5*). In the north area the variations appear slightly higher since only 65 % of the biomass is spread over the top three species. Gobies occurred rather often in both areas, but are significantly more important in the north area by numerical and biomass contribution. In the north also sticklebacks seem to be of higher importance compared to the south. The south area was dominated by shorthorned sculpin in all categories, when compared to the north were only 3 % of the biomass consisted of shorthorned sculpins. Why shorthorned sculpins are much more important prey species in the south compared to the north is unclear. But, since cormorants are both generalists and opportunists (Gremillet, 1997; Gremillet *et al.*, 1995), it is likely that the two different areas holds different species compositions due to possible differences in the benthic zone.

When comparing the results with the study of Hjernquist (2008), clear differences can be observed. Their results show that the diet consists of sticklebacks and eelpouts. Eelpout also seemed important in the study of Lehikoinen (2005). However, these studies show that eelpouts are important during the rearing phase. Lehikoinen also showed that in the “pre-hatched” stage, only 2 % of the prey biomass consisted of eelpout. But when rearing small young chicks, eelpout contributed to 49 % of the biomass. Before breeding, cormorants caught larger fish, and when rearing young they switched to smaller and slimmer fishes, like eelpout. Also, Harris & Wanless (1993) found that 99 percent of the biomass from chicks diet consisted of sandeel (*Ammodytes tobianus*). However, in adult shags during the same period they found that about half of the pellets also contained otoliths from other fish species. Otoliths from stomachs also implied that adult cormorants take a wider range of prey for themselves. With this said, differences between the result from this study and the chicks diet study of Hjernquist (2008) is not unexpected.

The total overlap between important species for fishery and cormorants appears relatively low in the result. Herring, which are of importance for commercial fishery (Rolf Gydemo, pers. comm, 2017), contributed to only 3 % of the biomass in the cormorant diet. As for recreational fishery, no trout, perch, European whitefish or northern pike were found in the diet of the cormorant. However, for the household fishing the overlap appears greater. Both European flounder and cod are species of importance for household fishing (Rolf Gydemo, pers. comm, 2017). These two species contributed to 46 % and 48 % of the biomass in the north and south area respectively. Other studies in the Baltic sea show high proportion of perch (Boström *et al.*, 2012a; Lehikoinen *et al.*, 2011; Lehikoinen, 2005). Surprisingly no perch were found in the pellets on Gotland. To which extent cormorant effect fish population in the Baltic sea has debated in many other studies (Östman *et al.*, 2012; Lehikoinen *et al.*, 2011; Vetemaa *et al.*, 2010). On Gotland, further studies are needed to evaluate cormorants effect on fish populations. This thesis only investigates in the post-breeding diet. Because cormorants diet probably varies over the season (Boström *et al.*, 2012a; Lehikoinen, 2005) additional sampling is needed.

4.2 Method - pellet analysis

The chosen method, of pellet analysis, has been debated to produce bias in both fish size and number (Duffy & Laurenson, 1983). To compensate for the biases, SCF and NCF were applied in this study. The possibility to use other sampling methods were limited. Regurgitated fish material is sampled at colonies from chicks during breeding season. This thesis was conducted after breeding and that method was therefore not possible. Analysing stomachs includes shooting of birds and is therefore a complicated process. Based on the budget, time and aim with the thesis, pellet analysis was an appropriate method. Pellet analysis is a common technique with many advantages. It is non-invasive, simple, and a large dataset can be provided over time at both colonies and roost (Barrett *et al.*, 2007). The fact that cormorants aggregate in groups both at colonies and roosts, makes the data collection easier. Pellet can also be sampled throughout the year, even during winter (Johansen *et al.*, 2001). Cormorants occur in Swedish water during the winter. Probably a mix of migrating birds from northern parts of Norway and Russia, but also from the Swedish population (Fransson & Petterson, 2001). Therefore, yearly collection of pellets should be possible on Gotland, but probably with less pellets during the winter.

The number of fish individuals in each pellet in this thesis was calculated by simply dividing the number of otoliths by two, since each fish holds two sagittae otoliths. This calculation will probably underestimate the number of individuals. A more accurate method is to separate left and right otoliths, and let the most abundant otolith represent the number of individuals in each pellet (Boström *et al.*, 2012a). Another way is to pair otoliths already when analysing based on size, orientation and wear etc. (Leopold *et al.*, 1998). These methods are time consuming and sometimes also problematic due to erosion, and were therefore not used here. The underestimations in this thesis arise if, for example, four left otoliths from cod is found in a pellet. The number of individuals is then no less than four. But when dividing by two, only two cod will be registered. However, the relative numbers per pellet is used and this method should therefore have small impact on the result, since all species are equally underestimated in each pellet.

Of all the otoliths, 22 % were classified as unknown. The majority of these otoliths were very small, probably by a combination of small original size and high erosion. Otoliths are worn to different degree dependent on their size, thickness etc. (Casaux *et al.*, 1995). Smaller otoliths are more easily eroded since they have a high surface area in proportion to their volume. Small otoliths in this thesis might belonged to smaller fish species such as sand lance, eelpout and gobies. The exclusion of theses otoliths results in underestimation of fish number and biomass of the smaller species.

Of the 397 pellets, 35 % were shown empty (*table 2*), with the majority from the north area (85%). Why pellets are produced when empty, is unknown. But pellets without otoliths and hard parts has occurred in other studies (Sonnesen, 2007; Hald-Mortensen, 2005). In these pellets, they found surprisingly high amount of shrimps. The authors suggest that low fish abundance can be the reason why cormorant start eating shrimps. Interesting here is that, the north area in this thesis showed high numbers of pellets without otoliths or other hard parts. Shrimp parts was observed in some, but not noted. In Sonnesen (2007) study from 2003, the amount of pellets containing shrimps and no otoliths, increased from 3.3% in May to 30 % in August. The amount of shrimps in the diet was though lower in 2005. However, the high amount of empty pellets in the north area may be explained by lower fish populations, and that cormorants instead feed on shrimps. To which extent shrimps are digested in the gastric system of a cormorant is unknown. To which extent cormorants on Gotland feed on shrimps should be further studied.

4.3 Method - fish size estimations

Eroded otoliths is not only a problem in identification. Erosion also affects the fish size estimations. Very few otoliths were assigned wear class 1, this was also a problem in the study of Boström *et al.,*(2012a) which also pooled class 1 and 2. By pooling class 1 and 2, and considered them as “original size” otoliths, produce an underestimation of fish size. This since, class 2 otoliths are considered original size, which they really are not. The average SCF for the four most abundant species were calculated to 1.17, which can be compared to 1.25 (Boström *et al.*, 2012a). There are, off course, uncertainties in the SCF, for example over-correction of wear by assigning too many small otoliths the highest wear-class (Leopold *et al.*, 1998). Still, the use of SCF produce better estimates than if no correction for wear would be used.

The regression slopes, used for fish size estimations, is not constructed from fishes in the study area. Whether this affect the fish size estimates, is uncertain. But regression slopes from Gotland might be more accurate for fish size estimations. Fish size estimation of otoliths only identified to family, are of course not entirely correct. This, since regression slopes are species specific and the species could not be determined. The chosen regression for otoliths only classified to family will produce biases if the chosen regression line is incorrect. But, I believe the results will be better than if not including them in the analysis.

4.4 Method - fish consumption

I calculated NCF based on captive feeding trial on cormorants by (Martucci *et al.*, 1993; Johnstone *et al.*, 1990). Feeding trials in captivity might not reflect the entire truth when it comes to recovery rates of otoliths (Zijlstra & Vaneerden, 1995). It has been discussed that captive birds are exposed to stress, which increase calcium secretion, and might therefore increase the calcium demands. In the beginning of the experiment by Zijlstra & Vaneerden (1995) the cormorants did not eject any pellets, suggesting that the stress contributed to the complete digestion of bones and otoliths. Another captive feeding trial showed that pellet production stopped after a short transportation of the cormorants, stress were suggested to be the reason (Trauttmansdorff & Wassermann, 1995). The uncertainties in the captive feeding trials will obviously contribute to uncertainties in the calculated NCF in this thesis. Also, the regression line between OW and RR show a rather weak degree of explanation 69 % (*figure 2*). However, it is the only available data on recovery rates of otoliths in cormorants, as far as I know. Consequently, the NCF calculated and applied to this thesis will not show the absolute truth when it comes to fish consumption. Sticklebacks could not be corrected for since they were identified by fin spines, and no correction factors could be used. Also, no correction factor for cod were used since the regression resulted in a NCF of 0.8. Cod otoliths probably don’t show a recovery rate of 100 % in reality, therefore the Cod is most likely slightly underestimated. By applying NCF I believe the results will come closer to the truth than if no correction factor were to be used. If additional, comprehensive studies of recovery rate of otoliths in pellets are conducted, the accuracy of NCF would increase and become useful in upcoming diet studies.

When using pellet analysis in diet studies, secondary consumption might be a problem (Oehm *et al.*, 2016). Secondary consumption can lead to errors in food web constructions when a predator feed on another predator, that in turn was feeding on another prey. This is not as big problem when analysing stomachs, since on intact fishes, it is possible to see which fishes were feed upon by the cormorant. This bias may not considerably affect the biomass in pellet studies, but it might affect the species composition and the number of fish eaten (Boström *et al.*, 2012a). In this thesis the assumption was made that all the prey detected in the samples was directly consumed.

5. Conclusion

The post-breeding diet of great cormorants on Gotland were analysed by using otoliths from regurgitated pellets. By biomass, the three most dominant species on the north were cod, European flounder and sticklebacks. In the south, shorthorned sculpins, cod and European flounder dominated the diet. Size correction factors (SCF) were applied to correct for fish size estimation, a method extensively used in earlier diet studies. However, numerical correction factors (NCF) to correct for fish numbers has not been used, as far as I know, in earlier cormorant diet studies. If additional studies on otoliths recovery rate in pellets is further studied in natural condition, the use of NCF can show higher accuracy and become more useful in future pellet diet studies.

The results contribute with valuable information regarding cormorants diet in the Baltic sea. this information can increase the understanding of how cormorants can affect fish populations and to identify possible management measures. It also gives objective information for the public that might bring clearness to the infected debate regarding cormorant diet. These results can also be used for further studies connected to cormorants or the Baltic sea. Competition between fishery and cormorant on Gotland appears highest on small scale fishery, where the overlap between household fishing and cormorant diet was highest.

The chosen method makes is possible for additional long term studies, it is cheap, and large data set can be sampled rather easy throughout the year. Diet should be further monitored to detect changes that may be of importance for management measures for the ecosystem. This thesis cannot determine whether cormorants effect fish populations, or to which extent they compete with fishery. To fully evaluate the cormorants effect on fish populations and the competition between fishery on Gotland, additional studies are necessary.

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2017:8	Tall trees survival in relation to bottom-up and top-down drivers in Hluhluwe-iMfolozi Park, South Africa Författare: Petter Madsen
2017:9	Prevalence of *Borrelia burgdorferi* sensu latu in rodents from two areas with varying wild ungulate densities in Southern Sweden Författare: Jimmy Nyman
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