

# Diet of the Great Cormorant (*Phalacrocorax carbo sinensis*) at two areas at Lövstabukten, South Bothnian Sea, Sweden, based on otolith size-correction factors

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This study determines Cormorant (*Phalacrocorax carbo sinensis*) diet composition and prey size at two areas 6 km apart, at Bay Lövstabukten, Sweden, in 2005. The study entails the examination of 333 pellets and 2,669 regurgitated fish. To determine the size of the predated fish based on worn otoliths found in pellets, size-correction factors were applied. Regression slopes between fish size and otolith size were applied to estimate the original size of the predated fish. Both pellet-based and regurgitated-fish-based analyses suggested the same dominating prey species by biomass. Based on pellets, Herring (*Clupea harengus*; 32.5%), European Perch (*Perca fluviatilis*; 20.9%) and Eelpout (*Zoarces viviparus*; 18.5%) dominated the diet. Regurgitated-fish samples contained species that were not found in pellets. These were mostly species with small and easily-eroding otoliths, such as Three-spined Stickleback (*Gasterosteus aculeatus*) and Greater Sand Eel (*Hyperoplus lanceolatus*). Cormorant diet between the two areas differed, and within both areas there were gradual changes in diet composition between incubation, nestling, chick and fledgling phases.



## 1. Introduction

The Great Cormorant (*Phalacrocorax carbo sinensis*; hereafter “Cormorant”) re-established as breeding birds in Sweden in the late 1940s, after being brought to extinction around the end of the 19th century. They remained low in numbers until the mid 1980s when the population size started to increase (Lindell *et al.* 1995, Engström 2001, Nelson 2005). The most recent published estimate for

the Swedish Cormorant population was based on counts done in 2006 and suggests about 44,000 pairs (HELCOM 2009). Cormorants are opportunistic foragers and are able to rapidly exploit newly-emerging food resources (Leopold *et al.* 1998, McKay *et al.* 2003). They feed almost exclusively on fish (Jonsson 1979, Lindell 1997) and their daily diet consists of around 400–500 g fish per day during the breeding season (Grémillet *et al.* 1995, Ridgway 2010). The Cormorant diet

partly consists of commercially and recreationally important fish species, such as European Perch (*Perca fluviatilis*) and Northern Pike (*Esox lucius*) (Jonsson 1979, Lindell 1997) so that the expansion of the Cormorant population is perceived to be in conflict with fisheries and creates socioeconomic conflicts (Engström 1998, Saulamo *et al.* 2001, Eschbaum *et al.* 2003, BSRP/HELCOM 2005, Boström *et al.* 2009). The effects Cormorants have on fish stocks have been studied in Europe (e.g., Vetemaa *et al.* 2010) and at Swedish inland lakes (e.g., Engström 2001). Based on their opportunistic behaviour, the Cormorant diet can be expected to be similar in areas with similar fish communities. For example, Lehtikoinen *et al.* (2011) studied Cormorant diet from 2002 to 2010 at the Finnish coast of the Gulf of Finland and found that Eelpout (*Zoarces viviparus*), Roach (*Rutilus rutilus*), European Perch and Three-spined Stickleback (*Gasterosteus aculeatus*) dominated the diet. Similarly, Pūtys & Zarankaitė (2010) found that in a Cormorant colony at the Curonian Spit, Lithuania, Ruffe (*Gymnocephalus cernua*), European Perch and Roach dominated the diet.

Cormorant diet can be determined in a non-lethal manner by examining the mucus-coated pellets containing the hard material Cormorants do not digest, such as fish bones and otoliths that can be identified to species and from which prey size can be estimated (Duffy & Laurenson 1983, Barrett *et al.* 1990). Another method is to investigate material the birds regurgitate when disturbed; these contain undigested fish or otoliths (hereafter “regurgitated fish”). Both methods have their limitations. The proportion of the number of fish items varies in regurgitated fish, and these do not allow an estimate of meal size to be made (Barrett *et al.* 2007). However, with regurgitated fish, fish size can be precisely measured, while with otoliths one has to estimate the size by using a regression slope between otolith size and fish size. As otoliths often are worn due to stomach action before a pellet is produced, there is a risk of underestimating fish size by this method (da Silva & Neilson 1985, Jobling & Breiby 1986, Pierce & Boyle 1991, Barrett *et al.* 2007).

Published reports on Cormorant diet from the east coast of Sweden are scarce: before 2005 only one published study existed (Lindell 1997). Lindell's study was based on pellet material, and

the dominating species were European Perch and Ruffe. In the present study, the diet was analyzed based on both pellets and regurgitated fish found in Cormorant colonies. Size-correction factors on otoliths were applied and evaluated as an attempt to minimize the underestimation of fish size when otoliths are worn in stomach acids. Possible spatial and temporal variation in the diet was also examined between three colony islands and two areas within the Bay Lövstabukten in the northern Baltic Sea.

## 2. Material and methods

### 2.1. Study area

The studied Cormorant colonies were located at Bay Lövstabukten, within a 125-km<sup>2</sup> area with a maximum depth of 20 m. The bay has shallow areas (<3 m) with good conditions for recruitment of European Perch, Northern Pike and cyprinids (Cyprinidae). Vegetation along shorelines consists mainly of different species of reed, and the underwater vegetation is characterized by charales. Several areas in the bay are protected and thus in a rather pristine condition. However, there is some nutrient discharge from adjacent settlement and farmland areas, but the degree of eutrophication is considered low compared to most other areas along the coast (Hjelm *et al.* 2009).

In 2005, Cormorant colonies were located at two areas less than 6 km apart: the northern area with the island Skräkhällen (60°38' N, 17°40' E) and the southern area with the islands Hättan and Själstenarna (60°35' N, 17°42' E; Fig. 1). The southern area thus comprises two adjacent islands which were considered one colony. The colony islands had no trees, forcing Cormorants to nest on the ground. For the northern area the estimates for the number of breeding pairs was 400 and that of fledglings was 1,095. The corresponding numbers for the southern area were 577 and 957.

Materials were collected during the Cormorant breeding period which in 2005 occurred between mid-April and August. Pellets were collected between 21 April and 2 August. Due to the restricted availability of regurgitated fish, they were collected during a shorter period, 13 May to 27 July. Collections were mainly concentrated within the

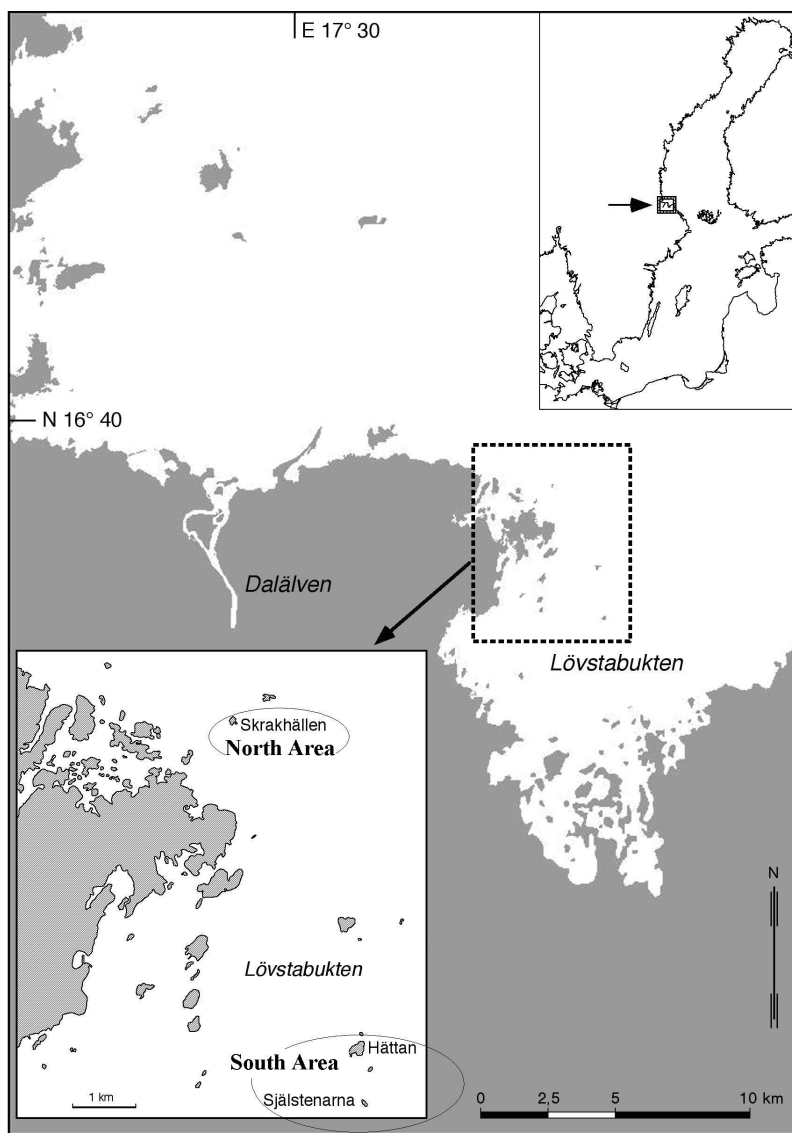


Fig. 1. Locations of the studied Cormorant colonies at the northern (Skrahällén) and southern areas (Hättan and Sjalstenarna) at Bay Lövstabukten, Sweden.

nesting areas (specified and referred to as colony areas in Boström *et al.* 2009). In an effort to minimize colony disturbance, the colonies were visited once or twice a week for approximately 30 minutes each time. Pellets and regurgitated fish were collected and examined in laboratory. Pellets were washed to sort out sagittal otoliths and other hard remains which were used to identify fish to the lowest possible taxon according to Härkönen (1986) and Leopold *et al.* (2001) in combination with the authors' own reference material.

Cyprinids were identified from otoliths and species were confirmed by the fish "chewing"

bones and pharyngeal teeth. Some otoliths could not be identified to species and others not even to family due to heavy wear from gastric acids. Right and left otoliths were noted and the most abundant were considered to represent the total number of fish in a pellet. The length and width of intact otoliths, along with the width of broken otoliths, were measured using a dissecting microscope. Regurgitated fish were identified and the length and mass were measured when fish were found intact or had minimal damage. If only length was measured the mass was calculated with length: mass regression slopes using the same sources as for the slopes for

otoliths. Fish that were too much digested to identify based on morphological characteristics were identified by otoliths, if remaining. For unidentified fish, mean length and weight of all fish was used.

## 2.2. Fish size estimates

Various methods have been suggested to reduce biases in fish-size estimates based on otoliths with digestion damage (e.g., Tollit *et al.* 2004). One method is to use grade-specific correction factors or size-correction factors (SCF) based on defined losses of morphological features on worn otoliths. This method does not account for size-specific wear of otoliths, but SCF has been extensively used in diet studies of marine mammals (e.g., Harvey 1989, Prime & Hammond 1990, Grellier & Hammond 2006, Lundström *et al.* 2007). Prior to the present study, this process has apparently only been applied to Cormorant research by Leopold *et al.* (1998) and Boström *et al.* (2012)

Here, each identified otolith was assigned to one of three wear classes based on otolith morphology described by Tollit *et al.* (1997). Otoliths of class 1 have minimal erosion with clear lobes and a well-defined sulcus; class 2 is characterized by signs of erosion with less pronounced lobes, a less distinct sulcus, more rounded rostrums and less pointed ends; and class 3 otoliths are highly eroded with no visible lobes or sulci and smoothed edges. A problem encountered here was that very few otoliths were not eroded: less than 2% represented wear class 1. The shortage of replicates made it impossible to calculate correction factors for the upgrade of otoliths to wear class 1. To solve the problem, classes 1 and 2 were pooled, and the correction factors were applied for class 3 only. Thus, resulting size estimates appeared as underestimates because class 2 otoliths – which were partly eroded – were considered original-sized otoliths. Wear classes 1 and 2 are hereafter referred to as “class 1+2” and wear class 3 as “class 3”. Wear-class specific SCF for species with sufficient amount of replicates [Herring, Ruffe, Smelt (*Osmerus eperlanus*), European Perch and Eelpout] were calculated, and these SCF values were used for respective species. For less abundant species an average of these SCF values

Table 1. Cormorant prey species and wear-class specific size-correction factors (SCF) for these species. The bottom row shows averages of the presented five species.

Species	Wear class, otolith width		Wear class, otolith length	
	1+2	3	1+2	3
Herring	1	1.23	1	1.20
Ruffe	1	1.20	1	1.20
Smelt	1	1.23	1	1.33
European Perch	1	1.37	1	1.47
Eelpout	1	1.21	1	1.26
Average	1	1.25	1	1.29

was used (Lundström *et al.* 2007). Assuming otolith size decreases proportionally to wear class, correction factors were calculated as the ratio between average otolith sizes of the different wear classes from the present dataset (Table 1).

To get an idea of how appropriate the application of our calculated correction factors was we looked at uncorrected and corrected otolith measurements separately and compared the estimated lengths of fish based on otoliths with wear classes 1+2 and 3. Wilcoxon’s tests were used, as the assumption of equal variance was not met. Theoretically, wear-corrected otolith data should result in no significant difference in fish-size estimates between wear classes 1+2 and 3, contrary to the data of uncorrected otolith sizes.

Fish mass and length were calculated using species-specific regression slopes between otolith width or length to fish length or mass, obtained from Leopold *et al.* (2001) and Härkönen (1986) for all species except Herring, European Perch, Whitefish (*Coregonus lavaretus*), and Sprat (*Sprattus sprattus*) where data by Lundström *et al.* (2007) were used. If available otolith width was prioritized over length as some species have a fragile rostrum which was often broken on the length. If the measured otoliths were larger than the otoliths used to produce the regression slope, they were downgraded to the size of the largest otolith used to calculate the slope. The reason was that the application of regression slopes would overestimate, considerably, the size of otoliths that were too large. Worn cyprinid otoliths are difficult to identify to species, therefore when no other bone structures could be identified or measured,

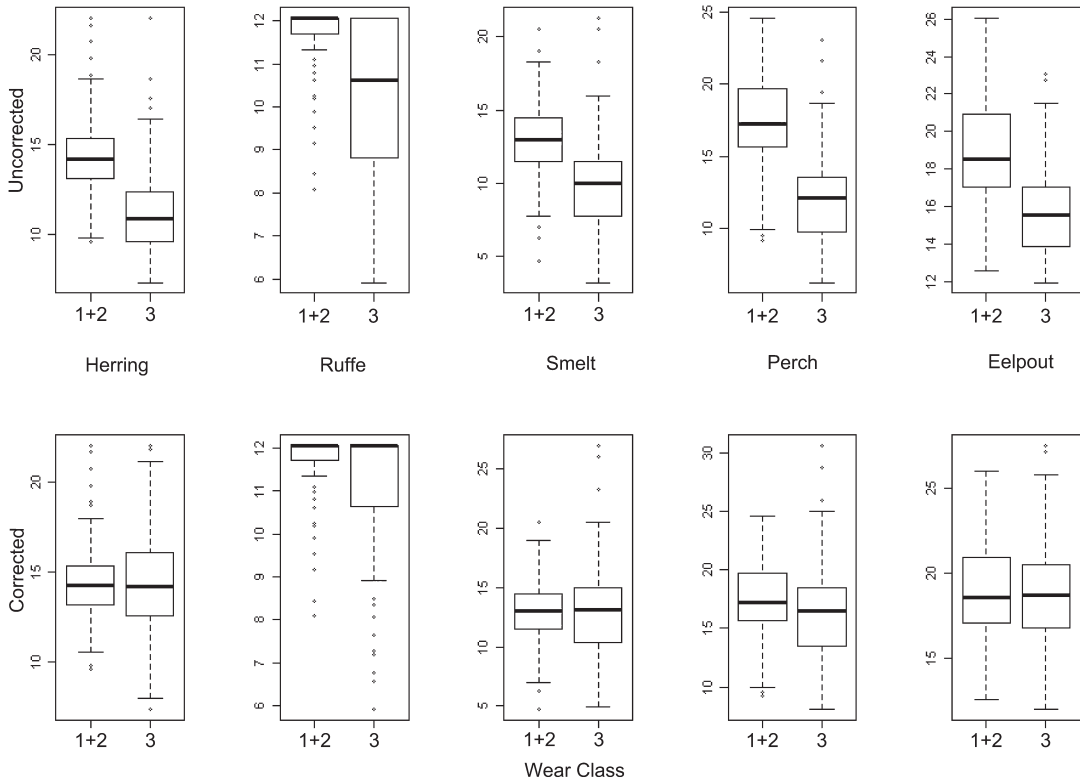


Fig. 2. Box plots for fish length as estimated from otoliths that are not corrected for wear (top), and length estimates after an application of correction factors for wear (bottom).

cyprinid total biomass was estimated using the mean of a sample of 20 undamaged cyprinids from regurgitated-fish samples.

### 2.3. Prey composition

Some pellets were devoid of otoliths and other prey remains and therefore not included in the calculations. To describe the biomass and number of fish, the relative number or biomass of each species to total numbers or biomass of all pellets ( $N_i\%$  and  $B_i\%$ , respectively) were used. Here the contribution of each pellet is proportional to the total numbers or biomass in each stomach (Lindström *et al.* 1998). This produces an estimate of uncertainty due to random processes and accounts for skewed distribution in the diet composition by applying a bootstrap technique (Haddon 2001, Santos *et al.* 2001, Lundström *et al.* 2007). For each iteration, contents of 333 pellets were drawn from the dataset and mean values of  $B_i$  and  $N_i$  of all

fish taxa in the diet were calculated. This was iterated 1,000 times and the 95% bias-corrected confidence interval was computed for each fish taxon.

During collections of regurgitated fish, it was not possible to differentiate between regurgitates because both adults, their young and neighbouring individuals sometimes regurgitated in the same spot. Also, sometimes regurgitate only constituted one fish individual. Therefore, instead of using several fish individuals in each sample, as for pellets, we treated regurgitated fish individuals separately. The relative numerical contribution ( $N_i\%$ ) and relative biomass contribution ( $B_i\%$ ) were calculated for each species separately for the northern and southern areas.

### 2.4. Spatial and temporal variation in the diet based on pellet material

A Bray-Curtis similarity matrix was constructed with 10,000 permutations on matrix data on spe-

Table 2. Prey species for the northern and southern study areas based on fish remains found in pellets. The sum of individual fish (No), frequency of occurrence (FO%), % of numerical contribution (Ni%) and biomass contribution percentage (Bi%) with 95% confidence intervals (CI) are shown. Length estimates show mean length (north and south combined) and are presented only for species for which an estimate could be calculated. The total sample included 240 pellets from southern and 93 from northern Lövstabukten, during the breeding period of 2005.

Species	Northern area				Southern area				Pooled, length		
	No	FO%	Ni%	Bi%	No	FO%	Ni%	Bi%	Min	Mean	Max
<i>Clupea harengus</i>	655	67.7	47.9 ± 9.2	36.5 ± 8.4	1,587	61.7	39.8 ± 6.0	28.5 ± 5.2	7	14	22
<i>Sprattus sprattus</i>	7	3.2	0.5 ± 0.8	0.2 ± 0.2	6	1.3	0.2 ± 0.2	0.1 ± 0.1	9	13	15
<i>Esox lucius</i>	4	2.2	0.3 ± 0.6	1.9 ± 3.8	2	0.4	0.1 ± 0.1	0.3 ± 1.0	34	35	36
<i>Osmerus eperlanus</i>	94	12.9	6.9 ± 6.9	4.5 ± 7.3	277	17.1	7.0 ± 2.8	4.2 ± 2.8	5	13	27
<i>Coregonus lavaretus</i>	4	2.2	0.3 ± 0.5	1.6 ± 3.5	4	0.8	0.1 ± 0.2	0.6 ± 0.9	21	26	29
<i>Salmo salar</i>	–	–	–	–	2	0.4	0.1 ± 0.1	–	–	–	–
Cyprinidae	63	12.9	4.6 ± 5.4	5.5 ± 6.4	159	18.3	4.0 ± 1.4	4.7 ± 1.6	–	–	–
<i>Trigloporus quadricornis</i>	2	1.1	0.1 ± 0.4	0.3 ± 0.7	14	1.7	0.4 ± 0.4	1.4 ± 2.1	15	17	20
<i>Myoxocephalus scorpius</i>	2	1.1	0.1 ± 0.4	0.4 ± 0.9	6	0.8	0.2 ± 0.2	0.5 ± 1.6	5	17	22
<i>Gymnocephalus cernua</i>	51	21.5	3.7 ± 1.9	2.9 ± 1.5	598	37.9	15.0 ± 3.8	10.9 ± 3.1	6	11	12
<i>Perca fluviatilis</i>	79	22.6	5.8 ± 2.8	14.9 ± 7.8	434	42.5	10.9 ± 2.3	27.0 ± 4.7	8	17	31
<i>Sander lucioperca</i>	–	–	–	–	2	0.4	0.1 ± 0.1	0.1 ± 0.3	–	–	–
<i>Zoarces viviparus</i>	270	48.4	19.7 ± 6.1	21.7 ± 8.0	581	39.2	14.6 ± 3.0	15.3 ± 3.8	12	19	28
<i>Ammodytes tobianus</i>	12	3.2	0.9 ± 1.2	0.2 ± 0.4	14	1.7	0.4 ± 0.5	0.2 ± 0.3	–	–	–
Osteichthyes	125	44.1	9.1 ± 4.0	9.4 ± 4.5	299	47.1	7.5 ± 1.6	6.3 ± 1.4	–	–	–
Total	1,368		100	100	3,985		100	100	5	18	36

cies-specific, relative biomass proportion per pellet, based on mass estimates calculated on otoliths corrected for wear. To test for differences in diet between islands, the two areas, and different breeding phases (time period, TP; four phases) an one-way non-parametric permutational multivariate analysis of variance (PERMANOVA), using the Bray-Curtis similarity indices, was performed with the adonis function available in the vegan package in R 2.10.0 (R Development Core Team 2011).

Based on field observations, the breeding cycle could be divided as follows: (1) egg incubation phase (24 March–4 May), (2) nestling phase (18–23 May), (3) chick phase (2 June–30 July), and (4) fledgling phase, when chicks are large enough to leave the nest but still remain at or near the colony (6 August–18 October). A preliminary analysis showed that the Cormorant diet was similar among colonies in the southern area, but was different between the southern and northern areas. Therefore the two areas were treated separately in post hoc analyses. Biplots of Constrained canonical Analysis of Principal coordinates (CAP) were produced

using the Bray-Curtis similarity index to visualise the difference in diet between time periods for the two areas. The CAP was done using the capscale function in vegan (R Development Core Team 2011).

### 3. Results

#### 3.1. Fish-size estimates

Without correcting for wear, the fish-length estimates based on otoliths were different between classes 1+2 and 3 (Table 1). Herring ( $W = 770,737.5$ ,  $p < 0.0001$ ), Ruffe ( $W = 51,427$ ,  $p < 0.0001$ ), Smelt ( $W = 21,169$ ,  $p < 0.0001$ ), European Perch ( $W = 36,015$ ,  $p < 0.0001$ ), Eelpout ( $W = 71,721.5$ ,  $p < 0.0001$ ). For the length measurements corrected for wear, there was a difference for European Perch ( $W = 24,249$ ,  $p = 0.0005$ ) and Eelpout ( $W = 48,985$ ,  $p = 0.016$ ) but not for Herring ( $W = 438,838.5$ ,  $p = 0.5017$ ), Ruffe ( $W = 36,329$ ,  $p = 0.27$ ) or Smelt ( $W = 13,626$ ,  $p = 0.726$ ). Fig. 2 illustrates that the application of correction

Table 3. Prey species of Cormorants on the northern and southern areas at Bay Lövstabukten, Sweden, based on regurgitated fish. Number of individuals (No), numerical contribution percentage (Ni%), biomass contribution percentage (Bi%). On columns under "Length", the minimum, mean and maximum length (in cm) of fish is presented. N/A = not estimated.

Species	North			South			Pooled, length		
	No	Ni%	Bi%	No	Ni%	Bi%	Min	Mean	Max
<i>Clupea harengus</i>	471	34.18	22.25	414	32.07	15.87	9	12	18
<i>Esox lucius</i>	0	0	0	3	0.23	2.58	N/A	N/A	N/A
<i>Osmerus eperlanus</i>	1	0.07	0.04	1	0.08	0.03	N/A	N/A	N/A
<i>Coregonus lavaretus</i>	6	0.44	3.33	1	0.08	0.46	N/A	N/A	N/A
<i>Salmo trutta</i>	2	0.15	0.61	0	0	0	20	20	20
<i>Abramis bjoerkna</i>	5	0.36	0.60	22	1.70	2.49	12	14	16
<i>Leuciscus idus</i>	3	0.22	0.28	9	0.70	0.71	14	14	14
<i>Rutilus rutilus</i>	1	0.07	0.23	16	1.24	1.88	15	16	18
Cyprinidae	11	0.80	1.50	35	2.71	3.95	13	15	16
Cottidae	1	0.07	0.31	0	0	0	N/A	N/A	N/A
<i>Belone belone</i>	1	0.07	0.00	0	0	0	N/A	N/A	N/A
<i>Gasterosteus aculeatus</i>	122	8.85	0.92	47	3.64	0.29	N/A	N/A	N/A
<i>Pungitius pungitius</i>	2	0.15	0.02	0	0	0	N/A	N/A	N/A
<i>Gymnocephalus cernuus</i>	10	0.73	0.70	26	2.01	1.35	7	10	14
<i>Perca fluviatilis</i>	111	8.06	20.55	277	21.46	39.08	9	14	24
<i>Sander lucioperca</i>	0	0	0	1	0.08	0.34	N/A	N/A	N/A
<i>Zoarces viviparus</i>	566	41.07	47.63	429	33.23	30.87	10	17	29
<i>Ammodytes tobianus</i>	58	4.21	0.97	2	0.15	0.03	8	11	14
<i>Hyperoplus lanceolatus</i>	3	0.22	0.01	2	0.15	0.00	N/A	N/A	N/A
Ammotydiadae	0	0	0	2	0.15	0.03	11	11	11
<i>Pomatoschistus minutus</i>	4	0.29	0.03	4	0.31	0.03	5	7	17
Total	1,378	100	100	1,291	100	100	5	14	29

factors brings the fish-length estimates of eroded otoliths (3) closer to the less eroded otoliths (1+2).

### 3.2. Prey composition

In total, 93 pellets from the northern area and 240 pellets from the southern area contained 5,353 specimens from 13 species and one additional family, Cyprinidae (21 pellets had no fish remains). Regurgitated-fish samples contained 2,669 specimens from 18 species and the additional families Cyprinidae, Cottidae and Ammodytidae.

The estimated mass of individual fish found in pellets ranged from a 0.6-g Smelt to a 739-g European Perch. The measured fish masses in regurgitated-fish samples ranged from a 1-g Sand Goby (*Pomatoschistus minutus*) to a 293-g Northern Pike. Regurgitated-fish samples contained addi-

tional species, such as the Three-spine Stickleback (Tables 2–3). The most dominant prey species by biomass were the same for both pellet and regurgitated-fish. The abundance order, based on percent of the total biomass, was Herring (32%), European Perch (20%) and Eelpout (18%) for pellets and Eelpout (39%), European Perch (29%) and Herring (19%) for regurgitated-fish samples. In total, for the two areas, these three species contributed 72% in pellets and 88% percent in regurgitated-fish samples.

### 3.3. Spatial and temporal variation in the diet based on pellet material

The diet varied significantly between islands, between the two areas (two southern islands pooled) and among the four breeding phases (periods, TP; Table 4). For the diet samples of the southern is-

Table 4. PERMANOVA (10,000 permutations) for the response of pellet samples to: i) different breeding phases (Period; TP1–4 in the post hoc test section; see text), ii) the three colony islands (Island; Skräkhällen, Hättan or Själstenarna), iii) between northern (Skrakhällen) and southern (Hättan+Själstenarna) areas, and iv) between different breeding phases in the southern colonies only. Post hoc tests were run separately for the northern and southern colonies to locate within-area differences between breeding phases.

Analysis	Variable	F	R	p
<i>PERMANOVA</i>				
All three colonies	Period	12.8229	0.03676	0.001
	Island	3.4855	0.01999	0.003
North and south	Period	12.8193	0.03676	0.001
	Area	5.8771	0.01685	0.001
Southern area	Period	9.9843	0.04025	0.001
	Island	1.0621	0.00428	0.356
<i>Post hoc tests</i>				
Northern area	TP1–TP2	9.0436	0.11159	0.001
	TP2–TP3	2.4304	0.0318	0.054
	TP3–TP4	2.8171	0.14216	0.031
Southern area	TP1–TP2	17.059	0.08083	0.001
	TP2–TP3	3.2205	0.01711	0.027
	TP3–TP4	3.2068	0.07094	0.026

lands only, the islands were similar but breeding phases varied significantly. Therefore, the northern and southern areas were treated separately when investigating temporal variation in diet.

Post hoc tests suggested significant differences in diet among the four breeding phases within both areas (Table 4). The CAP revealed gradual changes in the prey-species composition during the four breeding phases (TP 1–4; Fig. 3). During incubation, European Perch tended to characterise the diet in the northern area, while Smelt and Ruffe dominated in the south. At both areas, Herring dominated the diet during the nesting phase, but Eelpout appeared important at the chick-rearing period. During fledgling phase the Cormorants in the northern area switched to prey on cyprinids while in the southern area the diet was mainly characterised by Eelpout.

## 4. Discussion

### 4.1. The similarity of pellets and regurgitated-fish samples

In terms of the recovery of fish individuals, pellet material gave more information than regurgitated fish. Even though the most common species were

the same in both sample types, small fish were considerably more common in the latter. Thus, if the aim is to cover less common fish, or small fish with easily-eroding otoliths, a combination of methods should be applied. Another method that could be considered is an analysis of stomach content from shot birds.

Otoliths from different species erode at different rates depending on shape, size, thickness and time in gastric acids (Casaux *et al.* 1995), and hence recovery differs (Johnstone *et al.* 1990, McKay *et al.* 2003). Small otoliths have more surface area in proportion to their volume and are therefore more extensively abraded during the digestive process than large, robust otoliths (Jobling & Breiby 1986, Martyniak *et al.* 2003).

In captive-breeding experiments, McKay *et al.* (2003) concluded that the recovery of Brown Trout (*Salmo trutta*) otoliths in pellets may be as low as 2% of the total consumption. Erosion affects the estimates of both prey number and size. The number of prey species of Cormorants has been found to be 11–49% lower in pellets than in stomachs (Lunneryd & Alexandersson 2005). Seefelt and Gillingham (2006) compared pellets with both regurgitated fish and stomach contents and found that, by numerical frequency, the pellet and regurgitated-fish material showed different



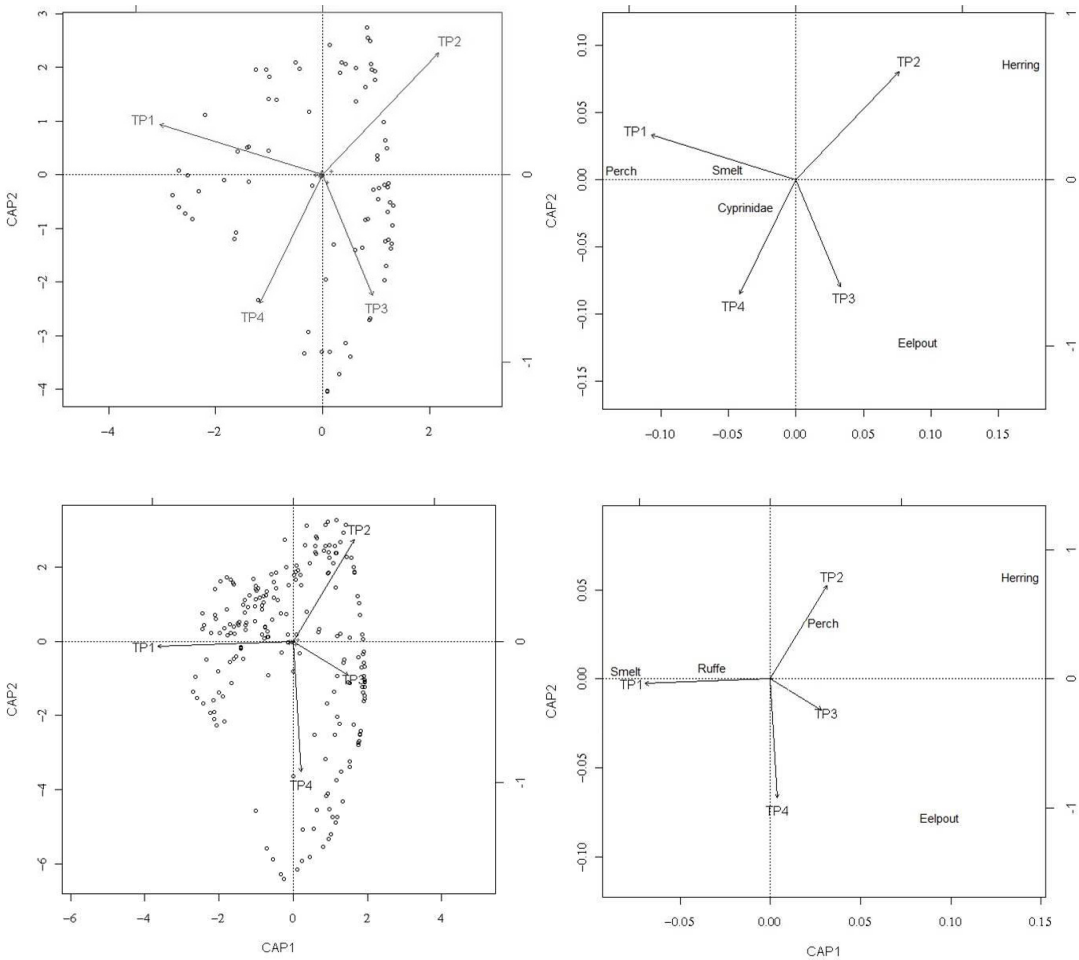


Fig. 3. CAP ordinations for the composition of Cormorant diet, based on a Bray-Curtis similarity matrix for fish biomass data: northern area (top) and southern area (bottom). The arrows indicate scores for each breeding phase (TP1 = incubation, TP2 = nestling, TP3 = chick, TP4 = fledgling). Each dot represents the diet of an individual Cormorant (left), and the enlarged picture (right) shows the fish species that varied most in the diet over the breeding cycle.

diet compositions. Also, percentage biomass contribution underestimated some species while overestimating others, compared to regurgitated-fish and stomach material. The results from Seefelt and Gillingham (2006) concur with the present study in that some species do not occur in pellets but are present in regurgitated-fish samples, and vice versa.

Regurgitated fish were only available during a short period, mostly during the end of June, during the chick phase. Therefore fish consumption, or length distributions of different species, was not statistically compared between pellets and regur-

gitated-fish samples. The regurgitated fish were most probably aimed to feed the chicks, or were regurgitated by the chicks. Pellets seem to reflect both adult and chick diet (Casaux *et al.* 1998) while regurgitated material mostly reflects chick diet only. Thus, the two methods may not be directly comparable.

#### 4.2. Spatial and temporal variation in the diet based on pellet material

The Cormorant diet at the two study areas had the same three dominating species but the order

(based on biomass) differed. During the present study Cormorants of the southern area were sometimes observed foraging south of the colony in the shallower parts of the bay, and Cormorants of the northern area foraged in deeper waters north or north-east from the colony. Most likely, a difference in foraging areas explains the observed differences in fish-prey-species composition between areas and breeding phases (time periods), even though the foraging areas of the studied colonies might have overlapped. The estimated foraging distance from a colony is around 15 km (Grémillet *et al.* 2004) which is more than the distance between the two study areas.

The diet, based on biomass, changed gradually during the breeding season, and this change was slightly different between the northern and southern areas. The most prominent difference was that European Perch dominated in the northern area when Cormorants were incubating, while at the southern area European Perch dominated later, i.e., when the Cormorants had nestlings. Ruffe and Smelt characterized the diet during the incubation phase at the southern area. The observation that Cormorants change their diet over the breeding season corroborates with other studies. For example, in a study conducted in the Gulf of Finland, Cormorant prey mainly constituted of Roach and European Perch before young hatched (Lehikoinen 2005). When the small chicks had hatched (May–June), adults also included Eelpout in the material they brought to nests. Later on they switched back to only Roach and European Perch but now towards larger prey individuals. In the present study, most of the observed changes in diet over the breeding season seem to follow the abundance of different fish species. For example, Eelpout migrates to shallow waters when the temperature reaches 4–12°C, which in the present study area occurs in May–June (Swedish Board of Fisheries' database). When water temperature exceeds 14°C, Eelpouts migrate to cooler, deeper waters (Vetemaa 1999). Water temperature may thus explain why Eelpout was a common prey in both areas in June, when the Cormorants had chicks. Herring also occurred in the same period and at the same time at both areas, i.e., during the nestling phase. Herring may thus have moved closer to the coast for spawning (Eero 1989) and thus become available for Cormorants.

### 4.3. Fish-size estimates, and other limitations

A problem with otoliths found in Cormorant pellets is that very few are un-eroded. This problem was solved (with an underestimation of fish size in mind) by including otoliths of wear class 3 as a reference for the original size of otoliths. For five species the upgrading for otolith width amounted to an average of 25%, which is comparable to the study of Lundström *et al.* (2007) on grey seal stomachs, performed with the same methods. Lundström *et al.* (2007) showed that, for three fish species, the otolith width should be upgraded by an average of 27% for wear class 3 and by 7% for wear class 2. Size-correction factors should clearly be applied in order to attain more reliable estimates of the original size of otoliths.

The regression slopes for otolith size versus fish size, based on fish from areas other than the present study may differ, which may lead to under- or overestimation of the size of the prey. To minimize this possibility, such regression slopes should be attained within the Cormorant foraging area in future studies. It is also important to calculate these slopes to cover considerably more size variation of fish that are predated on by the Cormorants.

With the size-correction factors used in this study an equal degree of erosion irrespective of otolith size was assumed. For example, wear class 2 otoliths from small and large European Perch were upgraded equally as much. The potential of this limitation in affecting fish-size estimates should be examined in the future, but applying correction factors is certainly better than not applying them.

A complicating factor in pellet-diet analyses is that pellet production varies seasonally with a decline during the breeding season, as Cormorants have a higher calcium demand when producing eggs (Simkiss 1975).

The pellets that are produced during that period contain less and more eroded otoliths than at other periods. Another concern in pellet analyses is the secondary consumption of fish, as some otoliths may have been from species depredated on by Cormorant prey (Barrett *et al.* 1990, Blackwell & Sinclair 1995, Leopold *et al.* 1998). This results in an overestimation of the number of fish eaten and in an underestimation of otolith loss. This may not be a severe bias in estimating total mass but it

might affect estimates of prey-species composition.

#### 4.4. Conclusions

By biomass, the dominant species appeared similar between pellet and regurgitated-fish samples. When determining the most commonly-occurring species either of these methods can be used. If the aim is to cover less common species, or species with small otoliths, these methods should be applied in combination or consider analysing stomach content from shot birds.

The present results showed that the most important prey at Bay Lövsbukten were Herring, European Perch and Eelpout. Diet composition varied over the breeding season, probably due to fish behaviour and varying abundance. It is not yet possible to establish the effect Cormorants have on fish populations, but the present study significantly contributes to the understanding of Cormorant diet at the Baltic Sea. Otolith wear appears a problem that can potentially be overcome by further assessing SCF as a method in future diet studies. Knowledge about Cormorant diet and estimates of fish stock sizes are crucial for the management of Cormorant populations in the near future.

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#### **Mellanskarvens (*Phalacrocorax carbo sinensis*) födoval i två närliggande områden i Norra Östersjön, beräknat med korrigeringsfaktor för slitage på otoliter**

År 2005 undersöktes mellanskarvens födoval i två områden i Lövsbukten, södra Bottenhavet, belägna 6 km från varandra. Studien inkluderar undersökningar av totalt 333 spybollar och 2 669 uppspydda fiskar. För att uppskatta storleken av fisken utifrån otoliter funna i spybollarna korrigerade vi först för slitage, orsakad av magsyror,

innan vi med hjälp av vikt- och längdregressioner från otolitstorlek uppskattade fiskens storlek. Utifrån vikten var det samma arter som dominerade i både spybollar och spyor. I spybollar var den viktigaste arten strömming (*Clupea harengus*; 32.5 %), följd av abborre (*Perca fluviatilis*; 20.9 %) och tånglake (*Zoarces viviparus*; 18.5 %).

I spyorna fanns ytterligare arter som inte hittades i spybollarna. Dessa var mindre fiskarter med små och lättsmälta otoliter såsom storspigg (*Gasterosteus aculeatus*) och tobiskung (*Hyperoplus lanceolatus*). Födoval skilde sig mellan de två undersökningsområdena. Inom varje område skedde också en gradvis förändring av födoval mellan olika perioder av häckningen, vid ruvning, när fåglarna hade nykläckta ungar, när ungarna var större men inte lämnade sina bon och när ungarna var flygfärdiga men fortfarande i behov av föräldrarna.

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