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RESEARCH ARTICLE

Stomach contents of the great cormorant *Phalacrocorax carbo* inhabiting northeastern Poland

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Abstract. The contents of 174 stomachs of great cormorants (*Phalacrocorax carbo*) inhabiting northeastern Poland were analyzed. Fish and hard parts of fish were found in most of the stomachs. (87.4%). Moreover, nematode and tapeworm parasites were observed in 76.4% and 4.6% of stomachs, respectively. Only 1.7% of stomachs were entirely empty. The fish identified in the stomachs were represented by 14 species. The most common species (72.2% frequency) in the diet of cormorants was European perch (*Perca fluviatilis* L.). Roach, *Rutilus rutilus* (L.) was the second most abundant prey (30.8%), followed by bream, *Abramis brama* (L.) (22.6%), bleak, *Alburnus alburnus* (L.) (16.5%), and vendace, *Coregonus albula* (L.) (13.5%), while nine other species occurred sporadically (frequencies < 7%). The number of fish species per stomach ranged from 1 to 5 (most often one species), while the number of individuals varied between 1 and 43 (most often 5–10 species). The length (SL) and weight of prey ranged from 4.0 to 62.0 cm and from 0.4 to 721.5 g, respectively. The most specimens were in the size range of 7–9 cm. The smallest specimens were perch and bitterling, *Rhodeus amarus* (Bloch), while the largest were pike and European eel, *Anguilla anguilla* (L.). Statistical analysis revealed significant differences in the length and weight of the fish consumed among the most abundant species.

Keywords: diet, fish, lakes, parasites, piscivorous birds, prey

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Introduction

The great cormorant (*Phalacrocorax carbo*) is a key piscivorous bird that is abundant in Polish lake districts (Krzywosz and Traczuk 2013). Predation by cormorants does not only affect the abundance and size-age structure of fish (Traczuk and Kapusta 2017), but it also changes food web dynamics (Seefelt et al. 2006, Boström 2013, Napiórkowska-Krzebietke et al. 2020, 2021). The diet of cormorants depends on the season (breeding and non-breeding status), general activity levels, distance to foraging sites, habitat, lake trophic status, environmental conditions, fish availability and structure (Seefelt et al. 2006, Čech et al. 2008, Gwiazda and Amirowicz 2010, Krzywosz and Traczuk 2012, Gaye-Siessegger 2014, Tverin et al. 2021), and the sex and age of the birds (Stewart et al. 2005). Accelerating climate change might also have a large impact on the dietary choices of the cormorants (Tverin et al. 2021).

The diets of piscivorus predators are examined with various techniques, including direct dietary assessment (pellets, regurgitated fish, stomach contents), direct feeding observational studies, and foraging ecology (food intake, daily expenditure, and novel biochemical methods such as DNA, stable isotope, and fatty acid analysis (Carss 1997, Barrett et al. 2007, Jepsen et al. 2010, Carss et al. 2012). These techniques are not entirely satisfactory and have specific disadvantages (Carss 1997).

The analysis of stomach contents can be a useful tool to investigate the cormorant diet because this method permits studying relatively fresh material (Carss et al. 1997, Seefelt et al. 2006, Oehm et al. 2016), provides an opportunity to collect information about birds, such as weight, age and sex, and also permits determining parasite infestations for each bird (Carss et al. 1997, Barrett et al. 2007). Dietary debris are digested to a lesser degree in stomachs than they are in pellets, which facilitates identification and size estimation (Barrett et al. 2007). Additionally, stomach content is the most appropriate method in studies focusing on ecosystems, because it provides a more reliable picture of dietary composition, including smaller species and individuals, throughout the year compared to other methods (Barrett et al. 2007, Boström 2013). Stomachs can provide a valuable source of dietary information, including undigested whole remains and hard parts of prey and macerated, semi-digested prey (Barrett et al. 2007). In some situations, stomach contents are the only way to assess the cormorant diet, for example, where pellets cannot be collected and where direct observations are difficult (Carss 1997). The greatest disadvantage is the necessity of killing birds. However, the investigation of the stomach contents of dead specimens is common practice in avian dietary studies (Oehm et al. 2016). The small number of birds used for stomach analysis might not be representative of a breeding population's diet. Additionally, the number of stomachs can be reduced further if some are empty (Carss 1997).

It is documented that a combination of two or more methods facilitates a more reliable dietary assessment. These are, for example, stomach and pellet analyses (e.g., Derby and Lovvorn 1997, Rudstam et al. 2004), stomach content and regurgitate fish (Seefelt et al. 2006, Boström 2013), and morphological and molecular analyses (Oehm et al. 2016). Each method provides different results concerning diets, but in terms of the presence and absence of possible prey types, stomach content data agree with both pellet and regurgitate data (Seefelt et al. 2006). Recent studies indicate that applying molecular approaches yields a wider prey spectrum than, for example, the morphological analysis of prey remains (Oehm et al. 2016), and it offers the possibility of detecting prey when their stomachs are empty (Ouwehand et al. 2004, Stewart et al. 2005). Additionally, molecular analysis clearly increases the number of fish species detected and also permits the identification of fish DNA in digested prey remains (Oehm et al. 2016).

The aim of the current study was to identify the stomach contents of cormorants feeding on several lakes in northeastern Poland. We hypothesized that prey fish species contained in stomachs differed significantly in size.

Material and methods

The studies were conducted in 2010 (from August 7 to September 22), 2012 (from August 1 to October 27), and 2014 (from April 14 to September 2). Stomachs of adult and juvenile cormorants were collected from birds hunting in several lakes situated in the Masurian Lake District (northeastern Poland). The number of cormorants killed varied considerably among the individual lakes from 2 to 45, while the total number of stomachs collected in the years studied was 77, 36, and 61, respectively. Cormorants were shot during daylight hours (generally between 13:00 and 20:00) by authorized hunters based on permits issued to fishing licensees. In total, 174 stomachs and 799 individuals of fish were analyzed. The dead birds were placed in plastic bags, frozen, and stored for further procedures. Later, each cormorant was thawed and then weighed and dissected. The digestive tract (esophagus and complete stomach) was removed from each bird and weighed. The entire contents of the stomach after dissection were analyzed for fish, hard parts (otoliths, pharyngeal teeth, burrs, jaws, bones), and parasites (nematodes and tapeworms). Undigested and partially digested fish were identified to the species based on morphological features and measured for standard length (SL ± 1 mm). The weight was calculated based on the length of the fish according to the formula:

$$W = k \times Ln$$

where: W – weight of fish; k – coefficient of regression related to particular species;

L – length of fish; n – coefficient of regression related to particular species. Values of k and n were used according to Wziątek (2003).

Data were statistically analyzed with STATISTICA software. The significance of differences in fish length (SL) and weight among the most abundant species was tested with one-way analysis of variance (ANOVA, P = 0.05) and Tukey's post-hoc test (p = 0.05). Pearson's correlation coefficient was calculated between the number of fish species and the number of individuals per stomach.

Results

The mean body weight of the cormorants collected was 2,292 ± 340 g (1,292–3,104 g). The mean weight of stomachs with food content was 174 ± 94 g (28–596 g). The contents of the stomachs collected are presented in Table 1. Apart from fish and fish remains, which were found in most of the stomachs (87.4%), nematodes were found quite often (76.4%), and tapeworms (Ligula sp.) were found in some of the stomachs (4.6%). The most common among the hard parts of fish were otoliths that were observed in 106 stomachs (60.9%). Only 1.7% of the stomachs were entirely empty.

Table 1

Number (n) and percentage of cormorant (*P. carbo*) stomachs with different contents collected in the Masurian Lake District (northeastern Poland)

Stomachs	n (%)
total	174
with fish and/or hard parts	152 (87.4)
with fish	133 (76.4)
with hard parts	111 (63.8)
without fish and hard parts	19 (10.9)
with nematodes	133 (76.4)
with tapeworm	8 (4.6)
empty	3 (1.7)

The fish found in the stomachs were represented by 14 species (Table 2). Only perch had a frequency slightly above 70%. Roach occurred in more than 30% of the stomachs, bream, bleak, and vendace were also relatively numerous, while nine species occurred sporadically and had frequencies <7%. The

Table 2

List of fish species found in the stomachs of cormorants (*P. carbo*), the number of stomachs in which fish species were found (SN), fish frequency in 133 stomachs with fish, number of fish individuals (N), standard length (SL) and weight (W) of consumed fish

Species	SN	Frequency (%)	N	SL (cm)	W (g)
European perch, *Perca fluviatilis*	96	72.2	403	4.0-19.0	0.9-125.0
Roach, *Rutilus rutilus*	41	30.8	142	6.0-17.5	3.1-99.9
Bream, *Abramis brama*	30	22.6	72	5.5-24.0	1.7-251.5
Bleak, *Alburnus alburnus*	22	16.5	57	5.5-12.4	1.8-22.1
Vendace, *Coregonus albula*	18	13.5	53	8.0-16.4	5.5-40.2
Pike, *Esox lucius*	9	6.8	9	8.7-40.0	10.7-721.5
Ruffe, *Gymnocephalus cernua*	7	5.3	31	4.3-8.3	1.7-10.1
Tench, *Tinca tinca*	6	4.5	9	5.5-26.5	3.6-474.6
Rudd, *Scardinius erythrophthalmus*	4	3.0	3	9.0-17.5	15.4-130.0
White bream, *Blicca bjoerkna*	3	2.3	6	6.5-8.7	5.3-12.0
European eel, *Anguilla anguilla*	2	1.5	2	48.0; 62.0	189.4; 420.8
European smelt, *Osmerus eperlanus*	2	1.5	10	6.7-9.3	
Common carp, *Cyprinus carpio*	1	0.8	1	17.3	
European bitterling, *Rhodeus amarus*	1	0.8	1	4.0	0.4

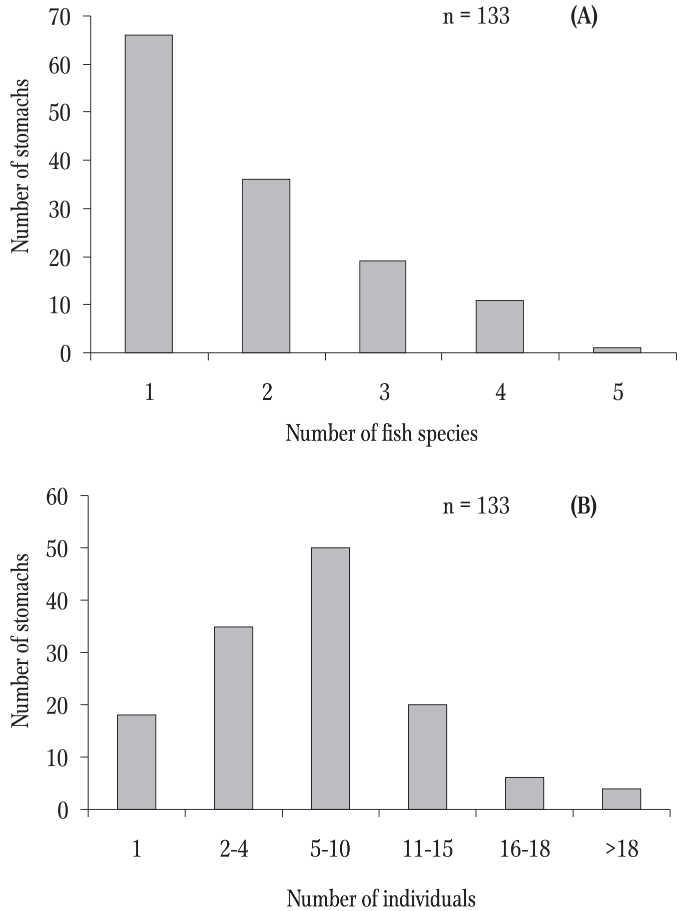

Figure 1. Distribution of the number of fish species (A) and the number of individuals (B) found in the stomachs of great cormorants (*P. carbo*) collected in the Masurian Lake District (northeastern Poland).

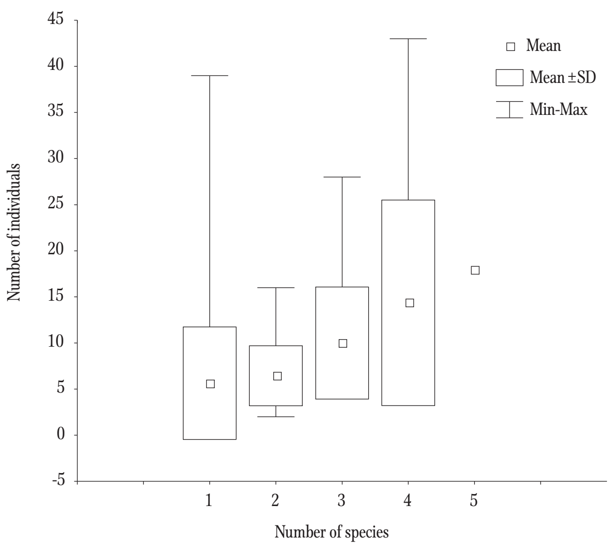

Figure 2. Mean ± standard deviations, minimum and maximum number of individuals in relation to the number of fish species found in the stomachs of cormorants (*P. carbo*) collected in the Masurian Lake District (northeastern Poland).

number of fish species per stomach ranged from one to five, while the number of individuals was 1–43 (Fig. 1). Among 133 stomachs, 66 (50%) contained only one species of fish (Fig. 1A). In 50 stomachs (about 38%), from five to 10 individuals were observed (Fig. 1B). The lowest mean number of individuals (5.6 inds.) was recorded in the stomachs with one fish species, while the highest (14.4 and 18.0 inds.) was noted in the stomachs with four and five fish species (Fig. 2). Generally, the number of individuals was positively related to the number of fish species ($r = 0.40$, $n = 133$, $P < 0.0001$).

The length (SL) and weight of the consumed fish varied in a wide range from 4.0 to 62.0 cm and from 0.4 to 721.5 g, respectively (Table 2). Among cormorant prey, eel had the longest body length (62 cm), while pike had the highest weight (721.5 g). On the other hand, perch and bitterling (4 cm each) had the

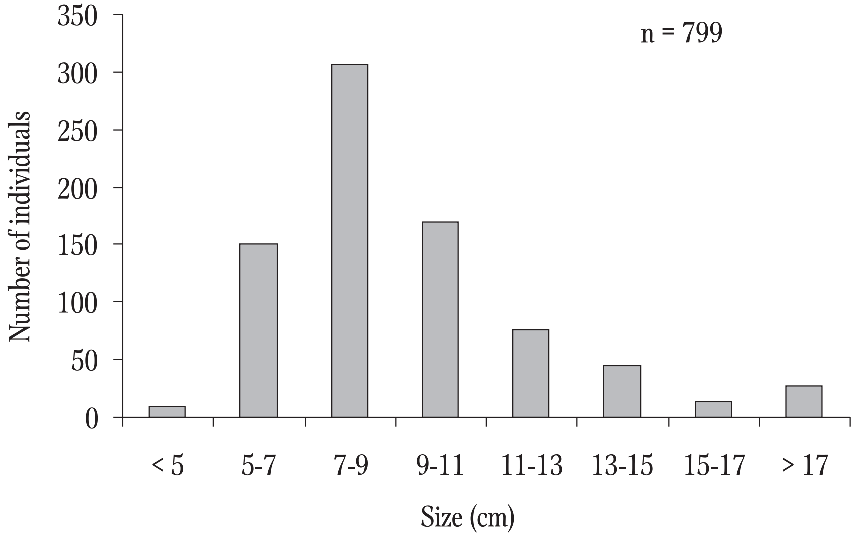

Figure 3. Distribution of standard length (SL) of fish found in the stomachs of great cormorants (*P. carbo*) collected in the Masurian Lake District (northeastern Poland).

Table 3
The number of individuals (N), mean values and standard deviations ± SD of the length (SL *standard length*) and weight (W) of consumed fish

Species	N	SL (cm)	W (g)
European perch	403	8.5 ± 2.0 A	12.1 ± 12.5 AB
Roach	142	9.2 ± 2.5 A	16.1 ± 16.9 AB
Bream	72	10.3 ± 4.1 B	26.2 ± 45.0 C
Bleak	57	8.6 ± 1.6 A	7.9 ± 4.5 A
Vendace	53	12.5 ± 2.3 C	20.2 ± 9.1 BC

ANOVA, Tukey's test; values with different letter indexes indicate statistically significant differences ($p < 0.05$).

smallest body length, and bitterling (0.4 g) had the lowest weight (Table 2). Among the total of 799 measured individuals, most specimens (307) were in the size range of 7–9 cm (Fig. 3), which accounted for 38% of the total number. Additionally, specimens with standard lengths of 5–7 cm and 9–11 cm were also quite numerous (151 and 169 individuals, respectively).

Differences in the length and weight of the five most abundant fish species (perch, roach, bream, bleak, and vendace) were statistically significant (ANOVA, $P < 0.05$) (Table 3). It should be noted that the length of vendace was significantly longer than bream, while the weight of vendace was significantly higher than bleak (Tukey's test, $P < 0.05$). The lengths and weights of bream were significantly higher than those of perch, roach, and bleak (Table 3).

Discussion

One of the most frequently used methods to determine cormorant diets is analyzing stomach contents (Boström et al. 2012). Literature data show that reliable estimates of the diet are possible from 12 to 15 stomachs (Marquiss and Carss 1997). The number of stomachs analyzed in various studies ranged from several tens (Stewart et al. 2005, Seefelt et al. 2006, Oehm et al. 2016) to several hundred (Bur et al. 1997, Boström et al. 2012, Gaye-Siessegger 2014).

In our study, the number of cormorant stomachs was representative of stomach content analysis and dietary assessment. In general, the weight of cormorants ranges between 1,706 g and 4,257 g and differs significantly between age and sex (Gaye-Siessegger 2014). Although the age of cormorants was not determined in our study, based on the weight of the cormorants, we can found that the birds were able to hunt independently in the water. Boström et al. (2012) showed that the average stomach content per cormorant is about 230–300 g, and it differs between the sexes. In the present study, the mean weight of the stomachs was clearly lower. These differences could have resulted from the different fish community structures that were under grazing pressure and the time of day the cormorants were shot. According to the results of some studies, about 15% of cormorant stomachs are empty (Stewart et al. 2005, Boström et al. 2012). However, these authors did not provide definitions of the term empty and whether this meant without fish or without fish and hard materials. In other studies, it was found that 9–10% of stomachs were without fish and hard parts (Gaye-Siessegger 2014, Oehm et al. 2016). In our study, 10.9% stomachs were without fish and hard parts, which indicated that expelled pellets contained the remains of fish caught on the previous day. The high percentage of stomachs containing hard parts (about 64%) could have indicated that fish prey was hunted on the same day and was completely digested. On the other hand, these hard parts could be the remains of fish hunted the previous day that were not expelled from stomachs as pellets, despite the fact that prey probably did not remain in stomachs for more than one day.

The cormorant diet is mainly composed of several of the most abundant, small-sized fish species (Martyniak et al. 2003, Russel et al. 2003, Gaye-Siessegger 2014, OvegÍrd et al. 2017). However, crayfish (e.g., *Faxonius limosus*) can also be an important food resource (Seefelt et al. 2006, Gaye-Siessegger 2014). The mean number of fish observed in stomachs is significantly lower than that in pellets (Johnson et al. 2010). This could suggest that cormorants hunt several times per day and fill their stomachs gradually, while pellets are the sum of all the prey from the previous day. According to Oehm et al. (2016), the average number of individual fish found per stomach was 11 ± 15 (range 1–60). In the present study, from 1 to 43 (mean of 7.3 ± 6.6) fish specimens were found in single stomachs. However, only one fish was found in 18 stomachs (13.5% of total), while the maximum number of individuals was recorded in one stomach only. Among 14 fish species, bitterling and common carp were represented by one specimen, while less numerous species, such as European eel and rudd, *Scardinius erythrophthalmus* (L.), were represented by two and three specimens, respectively. Similarly, Gaye-Siessegger (2014) demonstrated that 16 species were identified in the diet of cormorant breeding at Lower Lake Constance (Germany). In the diet of cormorants nesting in northeastern Poland, roach was the dominant component, followed by bream, tench (*Tinca tinca* (L.)), perch, and Northern pike, which accounted for 31.6, 26.6, 11.4, 10.9, and 8.4% of the total biomass, respectively (Krzywosz and Traczuk 2010a). The most important species in the diet of cormorants nesting at Lake Constance were tench, followed by Northern pike, perch, and European whitefish (*Coregonus lavaretus* (L.)) (Gaye-Siessegger 2014). Our study showed that perch, roach, and bream were the most frequent species consumed by the cormorants. It is documented that the length and weight of fish-prey varies within a very wide range. The smallest specimens are usually about 3.5 cm long and weigh 2 g, while the largest can reach about 40–60 cm long and weigh up to 0.8–1.0 kg (Krzywosz and Traczuk 2010a, 2012, Gaye-Siessegger 2014, Oehm et al. 2016, Traczuk et al. 2016, Traczuk and Kapusta 2017). In the present study, the smallest specimens consumed by cormorants were bitterling and perch (4.0 cm), while the largest was pike that reached a length of 40 cm. The weight of the smallest individual (bitterling) was 0.4 g, while the largest (pike) was about 722 g. The high number of small perch caught by cormorants could negatively influence the recruitment of perch and thus reduce commercial fisheries yield (Gaye-Siessegger 2014).

Cormorants also feed on protected (Krzywosz and Traczuk 2010b, Delmastro et al. 2015) and economically valuable fish (Wziątek et al. 2010, Salmi et al. 2015). Fish of high commercial value were a considerable part (85%) of the diets of cormorants nesting at Lower Lake Constance (Gaye-Siessegger 2014). In our study, among the 799 prey examined, only one specimen (0.1%) belonged to the protected species; it was bitterling. However, as many as five species were commercially valuable: perch (50.4%); vendace (6.6%); pike (1%); tench (1%); European eel (0.3%).

As a significant host of bacterial, viral, and parasitic pathogens, cormorants can potentially be responsible for the transmission of pathogens among ecosystems, leading to decreased water quality and increased animal diseases and potentially posing threats to human health (Klimaszyk and Rzymski 2016). Studies on cormorants from two nesting regions in the Czech Republic showed a total of 19 species of helminth parasites in cormorants (Moravec and Scholz 2016). It was documented that about 92.5% of great cormorants from northeastern Poland were infected with nematodes represented by *Contracaecum rudolphii* (Kanarek 2011). A high percentage (86.7%) of different nematode species was recorded in the stomach of cormorants in Lake Biwa in Japan (El-Dakhly et al. 2012). Our results demonstrated that 76.4% of cormorants were infected with nematodes, while only 4.6% of cormorants had *Ligula* sp. in their stomachs.

The results of our study showed that the stomach content method used for the analysis of the cormorant diets can be a source of additional information about parasites infecting cormorant stomachs. Since the cormorant diet changes seasonally (Boström et al. 2012), analyzing stomach contents throughout the year is necessary to obtain a complete picture of the cormorant diet and to determine the impact of cormorants on fisheries and fish species (Gaye-Siessegger 2014). Consequently, as the final host of tapeworms, cormorants could be an important vector of parasites in areas they inhabit, and their presence could lead to the deterioration of fish condition and/or disturbances in ichthyofauna structure.

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