Spatial Patterns of Winter Diet of the Great Cormorant in Coastal Wetlands of Greece

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Abstract.—Diet of the Great Cormorant (*Phalacrocorax carbo*) was studied in three coastal wintering areas (Axios and Evros Deltas, Messolonghi Lagoon) of Greece, in order to assess spatial differences and commercial value of prey. Thirteen birds were collected from the Axios Delta, 28 from the Evros Delta, and 16 from Messolonghi Lagoon. Pellets were collected from the Evros Delta (26) and Messolonghi Lagoon (30). A variety of fish taxa were found in the samples, but only one or two dominated in Great Cormorant's diet, either by numbers or biomass. Grey mullets (Mugilidae and Golden Grey Mullet *Liza aurata*) were the most important prey by numbers and biomass in the Axios Delta; Giebel (*Carassius auratus gibelio*) dominated by numbers and biomass in the Evros Delta; whereas Boyer's Sand Smelt (*Atherina boyeri*) was most important by numbers and Mugilidae by biomass at Messolonghi Lagoon. Differences found in diet between areas are probably due to differences in prey species composition and abundance. Fish of high commercial value contributed in low proportions in Great Cormorant's diet, by numbers and biomass, being highest at Messolonghi Lagoon (22.4% by numbers, pellets; 11.5% by biomass, stomachs). The small overlap between the bird's diet and valuable prey suggests minimal competition with fisheries. *Received 18 May 2006, accepted 20 September 2006.*

Key words.—Great Cormorant, winter diet variability, commercial value of prey, Greece, *Phalacrocorax carbo*.

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The Great Cormorant (*Phalacrocorax carbo*) is a widespread fish-eating waterbird (Cramp and Simmons 1977; Johnsgard 1993). Its populations have been increasing, although stabilizing recently, since the 1970s throughout its European range (Debout *et al.* 1995; Van Eerden and Gregersen 1995; Marion 2003; Volponi and Addis 2003). Legal protection by the European Community and the increase in fish productivity due to eutrophication of aquatic habitats have been identified as the main reasons for the rapid growth of the Great Cormorant populations (Van Eerden *et al.* 1995; Russell *et al.* 1996). The bird's increased numbers along with its fish-eating habits have caused severe conflicts with angling and fisheries interests in many countries (Russell *et al.* 1996; Cowx 2003). Upon this development, much research on Great Cormorant's diet, energetics, and impact on fish populations has been conducted, especially during the last ten years (Baccetti and Cherubini 1997; Cowx 2003; Keller *et al.* 2003) and management and control plans formulated and applied (Kirby *et al.* 1996; Bildsøe *et al.* 1998; Keller and Lanz 2003; Marion 2003).

The Greek populations have followed an increasing trend, similar to their European counterparts, during the last three decades (Handrinos and Akriotis 1997; Liordos 2004). This increase has also led to complaints from the fishermen and fisheries industry. We know of only one study on the diet of the Great Cormorant in Greece. Goutner *et al.* (1997) analyzed the diet of Great Cormorant nestlings in the Axios Delta in 1993 and 1994. The emerging conflict combined with the lack of relevant information prompted an urgent need for dietary analyses. Therefore, the aim of this study was to 1) describe and compare the diet of Great Cormorant populations in three major coastal wintering areas of Greece and 2) evaluate the commercial value of the fish consumed so that to identify possible impact of Great Cormorants on local fisheries.

Methods

Study Area

The study was conducted in the Axios and Evros Deltas and at Messolonghi Lagoon (Fig. 1), all of them designated as Wetlands of International Importance under the Ramsar Convention.

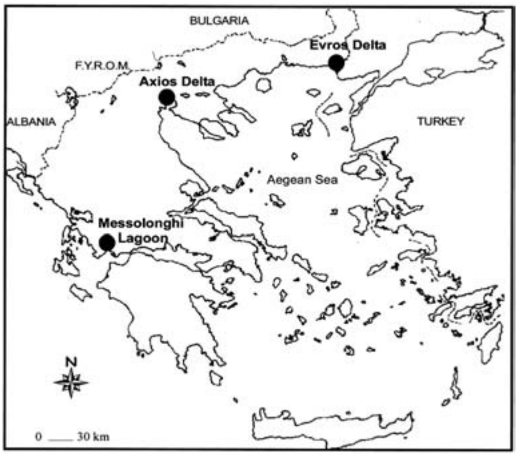

Figure 1. Map indicating the study areas within the context of Greece.

The Axios Delta (40°27'-40°38'N, 22°33'-22°52'E) belongs to a large wetland complex covering a total of 68.7 km^2, situated near the city of Thessaloniki (Athanasiou 1990). Great Cormorants roosted at sea over water on mussel aquaculture infrastructure (locally called as "beds"). The Evros Delta at the Greek-Turkish border (40°44'-40°51'N, 25°53'-26°8'E) is an extensive area (190 km^2) diverse in habitats (Zalidis and Mantzavellas 1994). Great Cormorants roosted on a poplar (*Populus* sp.) stand, on the west bank of the river's east branch. Messolonghi Lagoon (37°40'-39°40?N, 20°10'-21°30'E) belongs to the largest Greek wetland complex, and one of the largest in the Mediterranean basin, situated in southwest Greece, totaling 258 km^2 (Grimmet and Jones 1989). Two winter roosts were used in the area; one at Makropoula, a rocky outcrop, and another at the River Acheloos, on tamarisks (*Tamarix* sp.).

Diet Analysis

A total of 113 diet samples, 57 birds and 56 pellets, were collected during the wintering season. Obtaining large samples of birds is a difficult procedure, but Marquiss and Carss (1997) found that twelve to 15 stomachs could provide adequate estimates. We took therefore, under license by the Ministry of Rural Development and Food, 13 birds from the Axios Delta (October 2001), 28 from the Evros Delta (December 1999), and 16 from the Messolonghi Lagoon (February 2002). Pellets were collected from the Evros Delta (26, December 1999) and Messolonghi Lagoon (30, February 2002); they could not be retrieved from the Axios Delta because the birds roosted on mussel "beds" over water.

Bird specimens were collected two hours before sunset in all occasions, just before starting their return to the roost, to reduce the possibility of an empty stomach. Upon collection, the specimens were tagged with an identification number and then stored in a freezer at -20°C. On the day of diet analysis, the birds were thawed, dissected, their proventriculus and gizzard subsequently removed and contents taken according to Carss *et al.* (1997). Pellets were collected early in the morning, soon after the birds departed from their roost, and subsequently deep-frozen and processed according to Carss *et al.* (1997).

Intact fish prey were identified to the lowest possible taxon, measured to the nearest mm and weighed to the nearest 0.1 g. Otoliths and chewing pads, found in stomachs and pellets, were identified and measured (maximum length) to the nearest 0.1 mm using a dissecting microscope, and identified using Härkönen (1986), Veldkamp (1995a), and our own reference material. Otoliths were paired, assuming that those differing less than 0.2 mm originate from the same fish. Fish taxa found in the diet of the Great Cormorant are given in Table 1. Fish length and body mass were calculated using regression equations given in Dorel (1985), Härkönen (1986), Koutrakis and Sinis (1994), Petrakis and Stergiou (1995), Veldkamp (1995a), or constructed by the authors using intact fish found in stomachs or bought from the local markets (Table 2).

Stomach contents were analyzed by relative abundance by both numbers and biomass (numbers and biomass of each prey type in the sample), and frequency of occurrence (number of samples containing each prey type). Relative abundance in pellets was estimated only by numbers, due to lack of regressions estimating fish length and mass from chewing pads. The average fish prey biomass per stomach was also estimated. Fish length and mass for each area were calculated and compared using Kruskal-Wallis test (Zar 1999).

Fish prey taxa were classified according to their commercial value, following Goutner *et al.* (1997) and our own local markets' research (see Table 1). Proportions of the diet by numbers and biomass, according to commercial value, were then calculated to examine possible economic impact of the Great Cormorant.

All statistical analyses were performed using Statistica 6.0 software (StatSoft, Inc. 2001). Mean values are presented with ± one standard deviation (SD).

RESULTS

Diet of the Great Cormorant was composed of 20 different fish taxa, belonging to 13 families (see Tables 1, 3 and 5).

Stomach Contents

Composition of the Great Cormorant's winter diet differed considerably among the three coastal wetlands examined. In the Axios Delta, grey mullets (Mugilidae and Golden Grey Mullet *Liza aurata*) were the most important prey by numbers and biomass. Black Goby (*Gobius jozo*) was also important only by numbers whereas inversely Round Sardinella (*Sardinella aurita*) was more important by biomass (Table 3). The discrepancies between prey number and their contribution in biomass percentages were due to the relative size of fish prey (Table 4). Other fish prey was much less important. Mugilidae and Twaite Shad (*Alosa fallax*) were the most important prey by frequency of occurrence.

Table 1. Common and scientific names of the fish species found in the diet of Great Cormorants wintering in Greece. Commercial value of prey is also given (1: high; 2: medium; 3: low). Common and scientific names are taken from FishBase online (www.fishbase.org).

Common names	Scientific names	Commercial value
	Atherinidae	
Boyer's Sand Smelt	*Atherina boyeri*	3
	Blenniidae	
Peacock Blenny	*Blennius pavo*	3
	Carangidae	
Horse-mackerel	*Trachurus* spp.	3
	Clupeidae	
Twaite Shad	*Alosa fallax*	3
Pilchard	*Sardina pilchardus*	3
Round Sardinella	*Sardinella aurita*	3
	Cyprinidae	2
Bleak	*Alburnus alburnus*	3
Giebel	*Carassius auratus gibelio*	2
Carp	*Cyprinus carpio*	1
Roach	*Rutilus rutilus*	2
	Engraulidae	
Anchovy	*Engraulis encrasicolus*	3
	Gobiidae	3
Black Goby	*Gobius jozo*	3
	Moronidae	
Bass	*Dicentrarchus labrax*	1
	Mugilidae	2
Golden Grey Mullet	*Liza aurata*	2
	Mullidae	
Plain Red Mullet	*Mullus barbatus*	1
	Sparidae	
Gilthead	*Sparus auratus*	1
	Syngnathidae	
Pipefish	*Syngnathus* spp.	1
	Zeidae	
John Dory	*Zeus faber*	3

Stomachs examined (N = 13), contained on average 6.2 ± 1.4 (SD) fish (N = 80 fish, range 1-25), with an average fish prey biomass per stomach 242 ± 165 g (67-589 g).

In the Evros Delta, Giebel (*Carassius auratus gibelio*) was far the most important prey by numbers and biomass, Boyer's Sand Smelt (*Atherina boyeri*) only by numbers, whereas Mugilidae contributed mostly by biomass (Table 3). Mugilidae constituted the largest prey (Table 4). Giebel also dominated by frequency of occurrence. Stomachs examined (N = 28), contained on average 4.6 ± 2.8 fish (N = 130, 1-12), with an average fish prey biomass per stomach 227 ± 126 g (46-485 g).

At Messolonghi Lagoon, Boyer's Sand Smelt was most important by numbers, whereas Mugilidae contributed mostly by biomass (Table 3) being the largest and most frequent prey (Table 4). Stomachs examined (N = 16), contained on average 8.8 ± 17.6 fish (N = 141, 1-74), and an average fish prey biomass per stomach 309 ± 159 g (105-681 g).

Fish Length

The smallest fish found in the stomachs were a Black Goby (Axios Delta) and a Boyer's Sand Smelt (Messolonghi Lagoon); both 47 mm long (Table 4), and the largest was an

Table 2. Parameters of the equations ($y = a{\cdot}x^b$) estimated by the authors for the calculation of fish length and body mass (M) from fish and otolith length (FL: fork length; SL: standard length; OL: otolith length).

Fish species	Dependent variable	Independent variable	a	b	N	Range (mm)	R^2
Black Goby	M	SL	0.0842	1.1553	27	78-155	0.748
Boyer's Sand Smelt	M	OL	0.2351	2.6082	30	1.6-3.1	0.900
	M	FL	0.0000022	3.2582	30	53-92	0.966
	FL	OL	35.8543	0.7727	30	1.6-3.1	0.868
Giebel	M	FL	0.0001	2.6152	12	118-210	0.973

unidentified Mugilidae (240 mm; Evros Delta). Mean length of fish prey was significantly larger in the Evros Delta (131.8 ± 37.7 mm, N = 130) than the Axios Delta (115.9 ± 37.0 mm, N = 80) and the Messolonghi Lagoon (102.8 ± 47.1 mm, N = 141), Kruskal-Wallis (K-W) test (χ^2_2 = 33.89, P < 0.001). Most of the fish caught were in the length range 51-200 mm (98% for Axios and Evros Deltas, 92% for Messolonghi Lagoon).

Fish Body Mass

Body mass of fish prey varied from 0.6 g (Boyer's Sand Smelt, Messolonghi Lagoon) to 319 g (unidentified Mugilidae, Evros Delta). Mean fish body mass was significantly larger in the Evros Delta (49 ± 45 g, N = 130) than the Axios Delta (38 ± 47 g, N = 80) and the Messolonghi Lagoon (35 ± 45 g, N = 141), K-W test (χ^2_2 = 22.95, P < 0.001). Most of the fish prey weighed less than 100 g (about 90% for all the areas).

Pellet Contents

In the Evros Delta, Giebel and unidentified cyprinids were most frequent prey in almost similar numerical proportions (Table 5). The average number of fish from 26 pellets was 2.0 ± 1.0 (N = 51, 1-5). At Messolonghi Lagoon, Mugilidae were most important. Boyer's Sand Smelt, Bass (*Dicentrarchus labrax*) and Gobiidae followed with almost similar participation (Table 5). The average number of fish from 30 pellets was 3.9 ± 2.1 (N = 116, 1-8).

Commercial Importance of Prey

In all areas studied, fish of medium and low commercial value dominated among prey in terms of numbers and biomass (Fig. 2). Consumption of fish of high commercial value was highest at Messolonghi Lagoon. Fish of low value dominated numerically, but by biomass those of medium value were generally most important. At Messolonghi Lagoon Bass was the most important prey of high commercial value (see Tables 1 and 3).

DISCUSSION

Stomach contents and pellet analyses are considered appropriate methods for the qualitative analysis of avian diet but they should not be used for the calculation of daily food intake (DFI) rates, because a number of sources of error which lead to underestimation of prey biomass are involved, mainly: (1) uncertainty of bird feeding completion at the time of shooting (for stomachs), (2) erosion of fish remains, (3) under-representation of small species due to complete weathering of otoliths and other remains (Carss *et al.* 1997; Derby and Lovvorn 1997). However, we report estimates of average prey biomass per stomach found in our study due to the lack of such information from Greece. DFI of Great Cormorants has been found to vary greatly. In a review Feltham and Davies (1997) found that DFI varied from 130 g to 739 g (average 350 g). Grémillet and Plös (1994) and Grémillet *et al.* (1995), based on the energetic demands of *P. carbo sinensis*, estimated DFI at 238-588 g. The latter method is considered as the most accurate in the estimation of DFI (Carss *et al.* 1997). Values estimated in this study fell within the range reported from other studies.

Stomach samples contained on average more fish than pellets. The opposite trend

Table 3. Percent relative abundance, by numbers and biomass, and frequency of occurrence of the prey found in the stomachs of the Great Cormorant wintering in the Axios and Evros Deltas and at Messolonghi Lagoon. Total fish numbers (N) and biomass (g) taken from each area are also given.

	Axios Delta			Evros Delta			Messolonghi Lagoon		
Fish taxa	Numbers	Biomass	Frequency	Numbers	Biomass	Frequency	Numbers	Biomass	Frequency
	%			%			%		
Gobiidae	—	—	—	—	—	—	1.5	3.5	6.3
Black Goby	26.3	6.6	7.7	—	—	—	—	—	—
Peacock Blenny	1.3	0.4	7.7	—	—	—	—	—	—
John Dory	1.3	1.8	7.7	—	—	—	—	—	—
Trachurus spp.	1.3	10.2	7.7	—	—	—	3.5	9.6	25.0
Mugilidae	15.0	26.4	38.5	6.2	18.9	21.4	41.8	73.1	87.5
Golden Grey Mullet	22.5	11.2	23.1	—	—	—	—	—	—
Plain Red Mullet	2.5	6.7	7.7	—	—	—	—	—	—
Syngnathus spp.	3.8	2.9	7.7	—	—	—	—	—	—
Round Sardinella	16.0	24.0	23.1	0.8	1.0	3.6	—	—	—
Pilchard	—	—	—	6.8	4.2	3.6	—	—	—
Twaite Shad	5.0	9.3	30.8	—	—	—	—	—	—
Boyer's Sand Smelt	5.0	0.5	7.7	21.5	1.8	10.7	50.4	2.4	18.8
Giebel	—	—	—	56.2	66.6	82.1	—	—	—
Bleak	—	—	—	0.8	0.3	3.6	—	—	—
Roach	—	—	—	4.6	3.7	14.3	—	—	—
Carp	—	—	—	0.8	2.8	3.6	—	—	—
Anchovy	—	—	—	2.3	0.7	3.6	—	—	—
Bass	—	—	—	—	—	—	2.1	7.9	25.0
Gilthead	—	—	—	—	—	—	0.7	3.5	6.3
Total	N = 80	3,145 g	13 stomachs	N = 130	6,352 g	28 stomachs	N = 141	4,952 g	16 stomachs
Number of taxa		11			9			6	

Table 4. Standard length (mm) of intact items of the most important fish prey found in the diet of the Great Cormorant wintering in the Axios and Evros Deltas and at Messolonghi Lagoon.

	Mean ± SD	Range	N
1. Axios Delta			
Mugilidae	150.5 ± 30.9	120-215	12
Golden Grey Mullet	106.8 ± 20.1	59-130	18
Round Sardinella	168.4 ± 20.5	127-195	12
Black Goby	89.8 ± 22.6	47-134	21
2. Evros Delta			
Mugilidae	188.5 ± 27.6	154-240	7
Giebel	145.2 ± 24.9	67-200	12
Boyer's Sand Smelt	81.1 ± 12.5	59-107	28
3. Messolonghi Lagoon			
Mugilidae	144.1 ± 32.3	113-209	29
Boyer's Sand Smelt	63.0 ± 8.5	47-93	71

was considered more likely, since pellets reflect the complete bird diet of the previous day. However, this was not the case due to various factors affecting the number of fish in each sample type (e.g., fish size, fish species composition per area, otolith wear or loss; Carss *et al.* 1997; Derby and Lovvorn 1997).

The winter diet of the Great Cormorant included a considerable number of fish prey, but only a few of them usually composed the bulk of diet either by numbers or biomass. This agrees with other studies (e.g., Norway, Barrett *et al.* 1990; Lorentsen *et al.* 2004; Italy, Boldreghini *et al.* 1997; Greece, Goutner *et al.* 1997; Poland, Martyniak *et al.* 2003) and is due to the opportunistic foraging behavior of the Great Cormorant (Johnsgard 1993), which leads to the preponderance of the prey types mostly available and abundant in a particular area and season (Grémillet and Wilson 1999; Grémillet *et al.* 2001). Moreover, only two fish taxa, Mugilidae and Boyer's Sand Smelt, were present in all areas sampled, reflecting the spatial variation in species composition.

The fact that both in Evros Delta and Messolonghi Lagoon the same prey type, Giebel and Mugilidae respectively, dominated in both stomachs and pellets probably reflects use of the most abundant prey. Great Cormorants are thought to target prey patches of very high density (Grémillet *et al.* 2001) and the link between foraging performance and prey abundance is considered to be stronger

Table 5. Percent relative abundance by numbers and frequency of occurrence of the prey found in the pellets of the Great Cormorant wintering in the Evros Delta and at Messolonghi Lagoon. Number of pellets analyzed and total fish numbers (N) found in each area are also given.

	Evros Delta		Messolonghi Lagoon	
Fish taxa	% numbers	% frequency	% numbers	% frequency
Mugilidae	—	—	39.7	43.3
Cyprinidae	45.1	38.5	—	—
Giebel	41.1	57.7	1.7	6.7
Bleak	5.9	7.7	—	—
Carp	2.0	3.8	1.7	3.3
Gobiidae	—	—	17.2	23.3
Bass	—	—	18.1	23.3
Gilthead	—	—	2.6	3.3
Boyer's Sand Smelt	5.9	3.8	19.0	10.0
Total	N = 51	26 pellets	N = 116	30 pellets
Number of taxa	5		7	

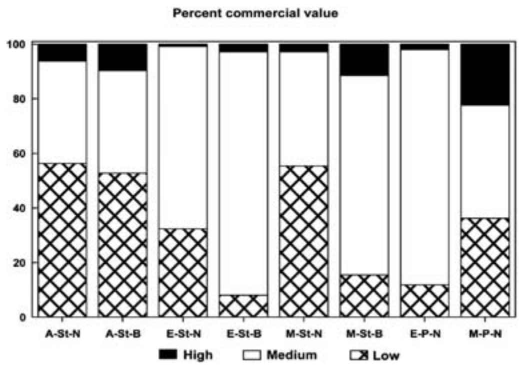

Figure 2. Commercial value of fish prey of the Great Cormorant in Greece. A: Axios Delta; E: Evros Delta; M: Messolonghi Lagoon; St: Stomachs; P: Pellets; N: % Numbers; B: % Biomass.

than in any other species of diving bird (Grémillet and Wilson 1999). In contrast, Grémillet *et al.* (2004) found that Great Cormorants in western Greenland did not forage on the most abundant prey, Capelin (*Mallotus villosus*), but preferred the less numerous bottom-dwelling Arctic Sculpin (*Myoxocephalus scorpioides*) and Arctic Staghorn Sculpin (*Gymnacanthus tricuspis*). They proposed that this foraging strategy is probably due to selection pressure favoring individuals with extraordinary foraging capabilities, and suggested that studies on prey abundance should be conducted in other areas as well.

The larger prey size (length and body mass) found in the Evros Delta than the other areas was probably due to the numerical preponderance of larger fish species in the former (i.e., Giebel and Mugilidae). The size of Great Cormorant fish prey has been found ranging from 0.5 g to 600 g in mass (Johnsgard 1993) and up to 600 mm in length (Cramp and Simmons 1977). The size distribution of individual fish found in the diet, in all areas, was similar to that found in other studies (Dirksen *et al.* 1995; Leopold *et al.* 1998; Lorentsen *et al.* 2004). The prevalence of certain size groups suggests greater abundance of certain prey types and/or sizes.

Our data suggested that the participation of commercially important fish in the Great Cormorant's diet did not exceed 12% by biomass and only at Messolonghi Lagoon reached to 22% by numbers (estimated from pellets). Similarly, other studies (Switzerland, Suter 1991; Germany, Keller 1995; Netherlands, Veldkamp 1995b) also found small participation of commercial fish in the diet, suggesting small economic damage. On the other hand, serious economic impact may occur in small areas of high fish concentrations such as intensive aquacultures, wintering ditches, small lakes, and reservoirs (Moerbeek *et al.* 1987; Cornelisse and Cristensen 1993; Kirby *et al.* 1996; Leopold *et al.* 1998; Knöesche 2003). A higher impact found in the area of Messolonghi Lagoon was due to the development of fishponds for commercially important species. Economic damage can be severe when high prey density is combined with adverse weather conditions. At Messolonghi Lagoon in winter 2001, after several days of low temperatures and frost, over 1,000 Great Cormorants were seen feeding at a fishpond stocked with Bass, Flathead Mullet (*Mugil cephalus*) and Gilthead (*Sparus auratus*) of commercial size (Dimitriou *et al.* 2003). Seventy-three percent of the stock sampled was found wounded by bird attacks, losing therefore their commercial value.

Overall, competition of the Great Cormorant with fisheries and fishermen seems minimal because of the small overlap between the bird's diet and valuable fish species. However, some economic damage may exist when large numbers of Great Cormorants occur in the vicinity of fisheries. At Messolonghi Lagoon area 5,000-6,000 Great Cormorants overwinter, in the Axios and Evros Deltas numbers counted reached 3,000 and 5,000 birds respectively (Liordos 2004). Concerns have been raised at these areas whether the fisheries will be sustainable in the presence of Great Cormorants. Our data suggest that the effects on local fisheries seem not to be important because of consumption of low-valued species. Nevertheless, before final conclusions are drawn, future studies should concentrate on the assessment of locality-specific impact size through the estimation of fish stock levels and total prey biomass removal (Davies *et al.* 2003).

This is the first study of the diet of wintering Great Cormorants in Greece. Results revealed the bird's opportunistic foraging behavior. A variety of prey types was consumed, reflecting the diversity and availability of fish species and therefore habitat types in a particular ecosystem. Differences in prey types and sizes among areas studied suggest regional variation in species composition. We infer small economic damage on fisheries based on qualitative diet analysis, which revealed low consumption of valuable species. However, in order to quantify impact more information on Great Cormorant population dynamics, daily food intake, diet variation, as well as fish population dynamics and behavior is needed.

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