



## Natural born indicators: Great cormorant *Phalacrocorax carbo* (Aves: Phalacrocoracidae) as monitors of river discharge influence on estuarine ichthyofauna

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### ABSTRACT

The ecological traits of piscivorous marine birds have been acknowledged to reflect ecosystem changes. We used the great cormorant as our indicator species in the Minho estuary (NW-Iberian Peninsula, Europe) to assess the temporal variation of their diet and the factors that could influence that variation. Pellets were collected in a night roost, located centrally in the estuary, during two consecutive wintering periods (2005–2006 and 2006–2007). The great cormorant population showed a high degree of feeding plasticity and most of the variation in cormorants' diet was attributed to river discharge fluctuations. Overall, during periods of increased river discharge, marine and marine opportunistic species disappeared from diet, whereas freshwater species increased. The cormorants in this study were using a roost in the middle of the estuary, so they were facing a changing food base over time, in accordance to variation in river discharges. The birds did not keep their diet constant but rather took what became locally available, notwithstanding their broad foraging range. Therefore, we suggest that great cormorants may be considered good samplers of local ichthyofauna and thus, temporal variation in the local prey can be followed by analyzing cormorants' diet.

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### 1. Introduction

Numbers of great cormorants *Phalacrocorax carbo* (Linnaeus, 1758) increased greatly throughout Europe during the last decades (Bregnballe et al., 2011), due to decreasing persecution and increasing food supplies through eutrophication, fish stocking (Russel et al., 1996) and the damming of waters (Farinha and Costa, 1999). This increase in bird numbers has been accompanied by frequent complains of damage to fish stocks and fisheries (Bregnballe et al., 2011; Kirby et al., 1996), often based on popular opinion rather than on scientific studies. Nevertheless, significant losses have been reported due to cormorant predation on fish farms (Lekuona, 2002; Moerbeek et al., 1987; Olmos et al., 2000) and when cormorants are present in high densities, they may be significant predators of juvenile fish in nursery areas (Barrett et al., 1990; Leopold et al., 1998).

The increasing trend in cormorant's population was also noticed in Portugal (SW-Europe), from 1000 individuals in the 1980's to 4000

individuals in the 1990's (Costa and Rufino, 1996), and since then there have been no systematic and thorough surveys on cormorant wintering population in Portugal. Like in other countries, complaints by Portuguese fishermen and aquaculture entrepreneurs about the impact of cormorant predation mostly lack scientific support. To our knowledge, there is only one study in Portugal where cormorant diet was analyzed in detail, revealing that economically important species were not the main prey of cormorants in a coastal lagoon (Ria Formosa, S-Portugal) and impacts in fish farms were not as severe as previously thought (Grade, 1996).

In Minho estuary (NW-Portugal), great cormorants are present throughout the year, with the highest numbers observed between November and February. Numbers in the estuary peak at about 350 between December and January (Lorenzo, personal communication) and both juveniles and adults winter here. This estuary is an important feeding and nursery area for fish and crustaceans (Cabral et al., 2007; Morais et al., 2011), some with high economic value (e.g. European eel *Anguilla anguilla* and European flounder *Platichthys flesus*), and is an important foraging ground for many birds, including the great cormorant.

Despite the relevance of evaluating the economic impacts caused by cormorant predation, the birds' diet can also be used as an

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ecosystem indicator. If we assume that higher trophic level animals are primarily controlled by bottom-up processes, then seabirds, and their biological traits, are indicators of ecosystem status and change (Piatt et al., 2007b). This has been shown in several studies of marine birds, relating to ecosystem health (Newman et al., 2007), oceanographic conditions (Montevecchi, 2007; Springer et al., 2007) and to the structure (Iverson et al., 2007; Montevecchi, 2007; Philippart et al., 2007; Piatt et al., 2007a) and dynamics of food webs (Diamond and Devlin, 2003; Robinette et al., 2007).

Ecosystem structure may vary over different time scales. Tidal and seasonal variations are usually strong and predictable but unpredictable changes can also be important. In estuaries, water levels, current velocities and salinity may vary with rainfall, draught or snow melt-offs, influencing the ecological conditions for fishes (Gillanders and Kingsford, 2002). Cormorants are generalist piscivorous, preying on marine, estuarine and freshwater fishes (Carss, 2003; Kirby et al., 1996 and references therein). When facing variable water levels and therefore, variations in prey abundance, availability and prey species composition, cormorants have two options: they can either “follow the fish”, moving downstream to feed if river discharges are high or upstream if the river runs dry; or stay put, and feed on whatever fish is present at their preferred feeding site. The first scenario suggests that the cormorants have a strong preference for certain fish species; the second that they have a strong preference for a certain part of the estuary. In a third scenario, cormorants feed over such large stretches of river, that no matter how the river discharge influences fish distribution, they will always find their preferred fish within their feeding range.

Under this framework, we have studied the temporal variation of cormorant diet in Minho estuary during high and low river discharge situations. The study is based on pellet analyses conducted at a single roost, during two consecutive wintering periods. Changes in the diet over time are reviewed in relation to river discharge and concurrent changes in the estuarine ecosystem, particularly those in food web structure and dynamics.

## 2. Methods

### 2.1. Study area

The River Minho is located in the NW-Iberian Peninsula (SW Europe) and drains a hydrological basin of 17,080 km<sup>2</sup>, 95% of which is in Spain and 5% in Portugal. The river extends for 343 km, 76 km forming the north-western Portuguese/Spanish border (Antunes et al., 2011). The estuary has an area of 23 km<sup>2</sup>, of which only 9% are intertidal areas. The limit of tidal influence is about 40 km inland, and the uppermost 30 km is a tidal freshwater wetland. The estuary is mesotidal, with tides ranging between 0.7 m and 3.7 m (Alves, 1996). The mean depth of the estuary is 2.6 m and the maximum depth is about 26 m (Antunes et al., 2011). The average annual freshwater run-off rate is 300 m<sup>3</sup> s<sup>-1</sup> (Ferreira et al., 2003).

Due to its ecological relevance, the Minho estuary and the international section of River Minho have been designated as a Natura 2000 site (EIONET, 2012). The estuary is also classified as an Important Bird Area (BirdLife International, 2011).

### 2.2. Sampling and laboratory procedures

Prior to this study, three cormorants night roosts were identified in Minho estuary: Ínsua island at the river mouth, La Vacariza island located in the center of the estuary (Ferreira, pers. com.) and an islet further upstream near São Pedro da Torre (Dias, 2007). For this study, only pellets collected at the central roost of La Vacariza were used, since it was the only site that provided data throughout the entire period of study (Fig. 1). Pellet analysis was used to evaluate the diet as data could be collected without disturbing the birds and it is

recognized as an appropriate method for temporal and spatial studies of avian diet (Barrett et al., 2007). However, the eroding effect of gastric acids on otoliths might bias data analysis by reducing the abundance of the rare preys and/or with small otoliths (Zijlstra and Van Erden, 1995).

Samples were collected monthly during two wintering periods (October–March) in 2005–2006 and 2006–2007. Pellets were also collected in August and September 2006. In January 2007 pellets were not collected due to logistic constraints.

Fresh pellets were collected, stored in individual plastic bags and kept frozen at –20 °C until examination. In the laboratory, pellets were thawed and the mucous dissolved in 1 M NaOH solution. After rinsing with tap water, the otoliths and other identifiable remains (e.g. vertebrae, pharyngeal bones) were sorted, air-dried and identified to the lowest taxonomic level possible, using Härkönen (1986), Prenda et al. (1997), Leopold et al. (2001) and our reference collection.

### 2.3. Data analysis

The minimum number of fish in each pellet was estimated using the otoliths only. Each otolith was identified as left, right or unknown and subsequently paired on the basis of species, orientation, size, shape and wear. All otoliths showed signs of wear, varying from only slight wear to extensive wear. The wear of otoliths was visually determined and divided in four classes according to Leopold et al. (1998, 2001): slight wear (class 1), moderate wear (class 2), heavy wear (class 3) and those in which size seemed to have no relationship with the original size (class 4). Pairs of otoliths, as well as unpaired left and right otoliths, were counted as one fish.

The frequency of occurrence (percentage of pellets with a given prey taxon) and relative abundance (percentage of a prey taxon in relation to all prey items in pellets) were determined to allow comparisons, since the sampling effort, (i.e., the number of pellets per month) was not constant throughout the study.

The lowest taxonomic level identifiable for all samples was the family. Thus, family will be the level described in the subsequent analysis. Non-parametric analysis of similarity (ANOSIM) was used to investigate seasonal patterns of cormorants' diet, according to three established factors: 1) river discharge (low, average, high- groups defined with a cluster analysis); 2) season (summer, autumn, winter); 3) wintering period (2005–2006, 2006–2007). Comparisons between wintering periods were limited to coincident months. The similarity matrixes used in these analyses were made after arcsine data transformation and setting the Euclidean distance as the similarity measure. Arcsine transformation is recommended when using relative frequency data (Zar, 1999) and Euclidean distance is a useful measure because it is not affected by outliers (Statsoft, Inc., 2011). Then an ANOSIM analysis was made to examine the existence of meaningful differences between the groups of each factor. Resulting R-values similar to 0 indicate small differences; R-values close to 1 indicate very large differences (Clarke and Warwick, 2001).

The most abundant families in cormorant diet were identified using SIMPER, which estimates the average contribution of each family to the similarity (typifying family) and dissimilarity (discriminating family) between groups of each factor. The ratio “similarity/standard deviation” (sim/st. dev.) and “dissimilarity/standard deviation” (diss./st. dev.) are useful measures of how consistently the family typifies or discriminates a group, respectively. Thus, ratios lower than 2 indicate that a family does not consistently typify the group (Clarke and Warwick, 2001). However, as the samples of this study were not real replicates but monthly estimates, a threshold of 1.5 was considered to be the indicator of temporal changes of family abundance in cormorants' diet (Chícharo et al., 2006). All these statistical analyses were conducted using the PRIMER 5 software.

A *t*-test, or the equivalent non-parametric Mann–Whitney test, was used to check for differences between the relative abundance

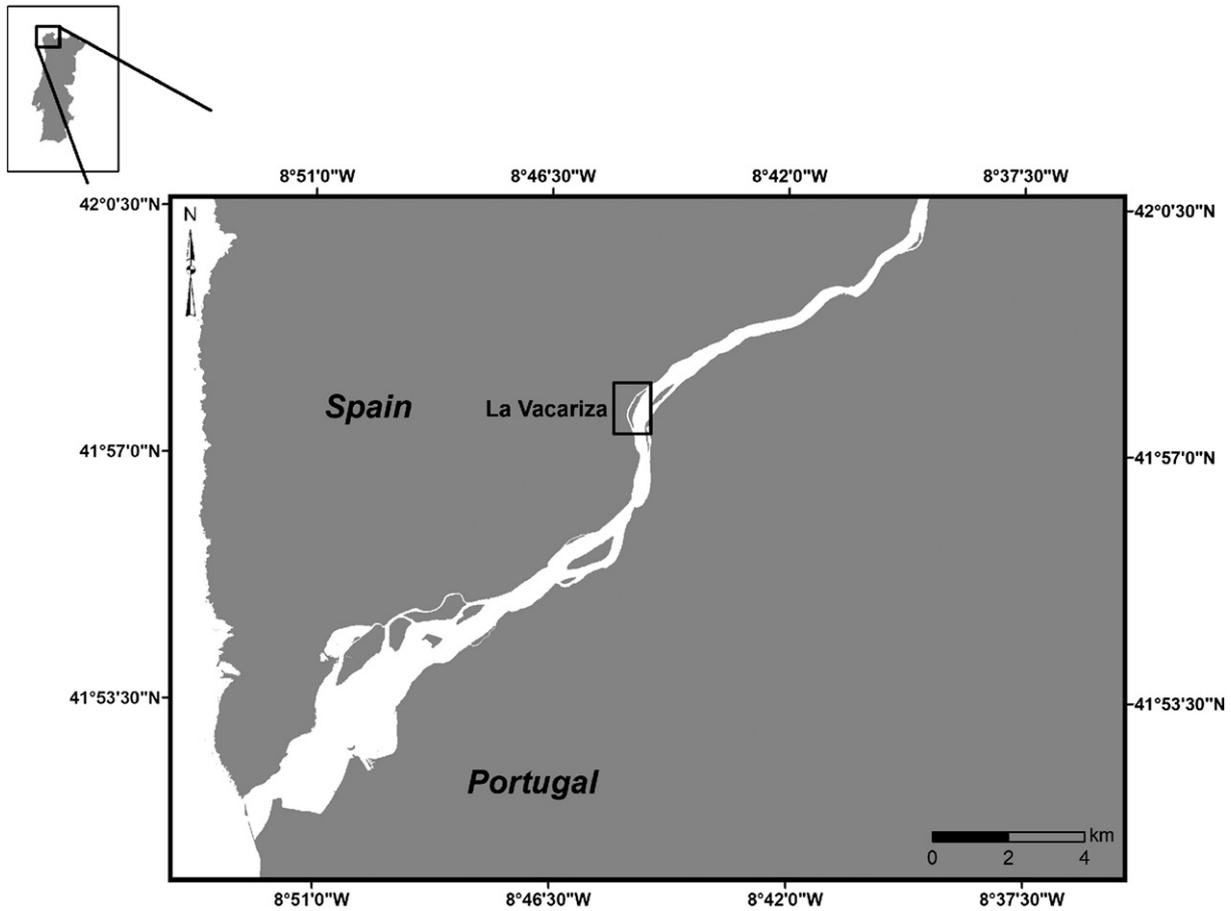


Fig. 1. Location of the great cormorants' night roost sampled in the Minho estuary (NW-Portugal, Europe).

(RA) and frequency of occurrence (FO) between wintering periods. The level of significance was 0.05 (Sokal and Rohlf, 1995). These tests used the RA and FO of the families with global average values higher than 10%, while prey families with average contributions lower than 10% were assigned to "Others".

3. Results

3.1. Characterization of Minho river discharge

During the first wintering period, river discharge varied between  $0.3 \times 10^9 \text{ m}^3$  (October 2005) and  $1.8 \times 10^9 \text{ m}^3$  (March 2006), i.e., 66% and 38% lower than the equivalent limits registered during the second wintering period, when the river discharge varied between  $0.9 \times 10^9 \text{ m}^3$  (October 2006) and  $2.9 \times 10^9 \text{ m}^3$  (December 2006) (Fig. 2). A cluster analysis (data not shown) defined three levels of river discharge: a) low river discharges ranged from  $2.0 \times 10^8 \text{ m}^3$  (August 2006) to  $4.4 \times 10^8 \text{ m}^3$  (November 2005); b) medium river discharges ranged from  $5.3 \times 10^8 \text{ m}^3$  (May 2006) to  $1.2 \times 10^9 \text{ m}^3$  (April 2006); c) high river discharges ranged from  $1.6 \times 10^9 \text{ m}^3$  (November 2006) to  $2.9 \times 10^9 \text{ m}^3$  (December 2006) (Fig. 2).

3.2. Great cormorant diet

A total of 260 pellets were collected during the sampled period, 32% of which were empty. Only fish were identified as prey. A total of 723 prey fish were identified, belonging to 17 families and 23 species, of which 14 were marine species, 6 were freshwater species and at least two were migratory species (Table 1).

During the 2005–2006 wintering period, Pleuronectidae were an abundant and frequent prey of great cormorants, mainly in October 2005 (RA = 0.50; FO = 0.75) and January 2006 (RA = 0.80; FO = 0.46) (Figs 3A and 4A). Although less abundant, Cyprinidae were a frequent prey, mostly in January 2006 (FO = 0.54) (Figs. 3A and 4A). However, in February and March 2006, the diet changed and Cyprinidae became the most abundant and frequent prey (RA<sub>Feb</sub> = 0.44; FO<sub>Feb</sub> = 0.27; RA<sub>Mar</sub> = 0.44; FO<sub>Mar</sub> = 0.67) and the RA and FO of Mugilidae also increased (RA<sub>Feb, Mar</sub> = 0.087; FO<sub>Feb</sub> = 0.20; FO<sub>Mar</sub> = 0.33) (Figs. 3A and 4A).

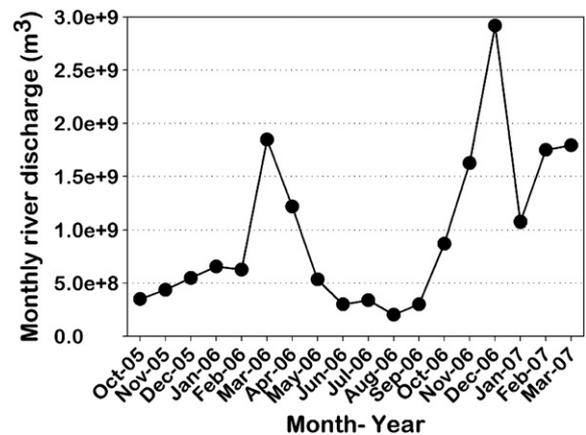


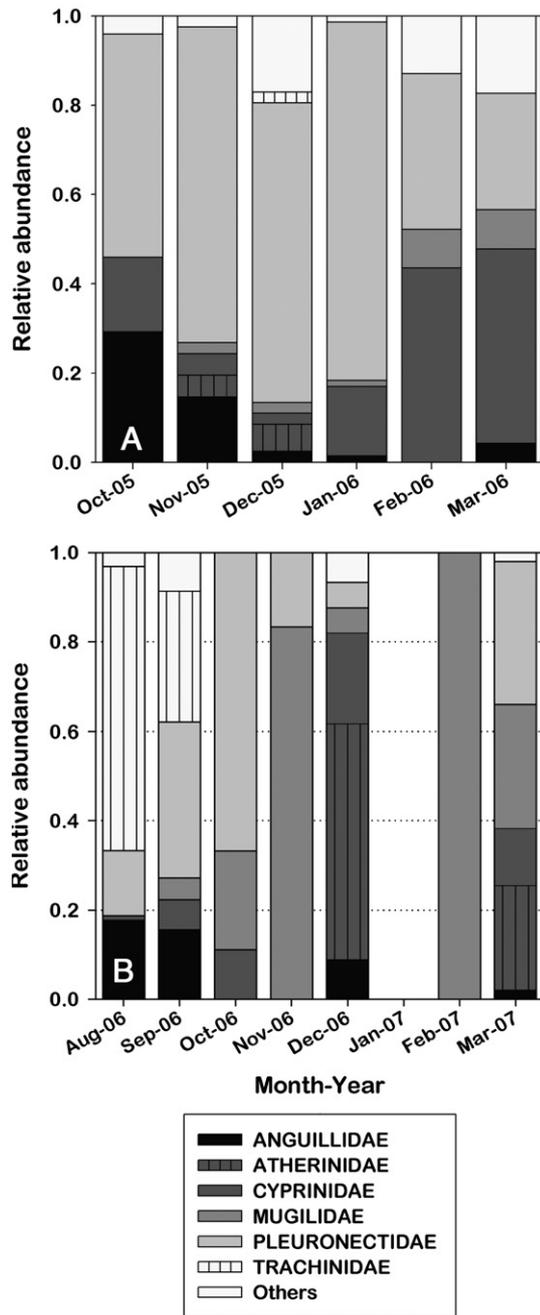
Fig. 2. Monthly river discharge of Minho estuary measured at Foz do Mouro hydrometric station, between October 2005 and March 2007 (INAG, 2007).

**Table 1**Fish identified as prey of *Phalacrocorax carbo* in Minho estuary (NW-Portugal) and respective ecological guild and vertical habitat, following the classification of Antunes and Rodrigues (2004) and Engelhard et al. (2010).

Order	Family	Species	Ecological guild	Vertical habitat	
Anguilliformes	Anguillidae	<i>Anguilla anguilla</i> (Linnaeus, 1758)	Catadromous	Demersal	
Atheriniformes	Atherinidae	<i>Atherina</i> sp.	Marine opportunistic	Pelagic	
Beloniformes	Belonidae	<i>Belone belone</i> (Linnaeus, 1761)	Marine adventitious	Pelagic	
Cypriniformes	Cobitidae Cyprinidae	<i>Cobitis paludica</i> (De Buen, 1930)	Freshwater	Benthopelagic	
		<i>Cyprinus carpio</i> (Linnaeus, 1758)	Freshwater	Benthopelagic	
		<i>Gobio lozanoi</i> (Linnaeus, 1758)	Freshwater	Benthopelagic	
		<i>Squalius</i> sp.	Freshwater	Benthopelagic	
		<i>Tinca tinca</i> (Linnaeus, 1758)	Freshwater	Demersal	
		n.i.			
Gadiformes	Gadidae	<i>Trisopterus</i> sp.	Marine	Benthopelagic	
Gasterosteiformes	Gasterosteidae	<i>Gasterosteus aculeatus</i> (Linnaeus, 1758)	Freshwater	Benthopelagic	
Perciformes	Ammodytidae Callionymidae Gobiidae	<i>Ammodytes tobianus</i> (Linnaeus, 1758)	Marine opportunistic	Benthopelagic	
		<i>Callionymus lyra</i> (Linnaeus, 1758)	Marine opportunistic	Demersal	
		<i>Aphia minuta</i> (Risso, 1810)	Marine opportunistic	Pelagic	
		<i>Gobius niger</i> (Linnaeus, 1758)	Marine	Demersal	
		n. i.			
			Moronidae	<i>Dicentrarchus labrax</i> (Linnaeus, 1758)	Marine opportunistic
Pleuronectiformes	Mugilidae  Trachinidae Bothidae Pleuronectidae	<i>Chelon labrosus</i> (Risso, 1827)	Marine opportunistic	Pelagic	
		<i>Liza ramada</i> (Risso, 1827)	Marine opportunistic	Pelagic	
		n. i.			
		<i>Echiichthys vipera</i> (Cuvier, 1829)	Marine opportunistic	Demersal	
		<i>Arnoglossus laterna</i> (Walbaum, 1792)	Marine	Demersal	
		<i>Limanda limanda</i> (Linnaeus, 1758)	Marine	Demersal	
Salmoniformes	Soleidae Salmonidae	<i>Platichthys flesus</i> (Linnaeus, 1758)	Catadromous opportunistic	Demersal	
		n. i.			
		<i>Solea solea</i> (Linnaeus, 1758)	Marine opportunistic	Demersal	
		<i>Salmo trutta</i> (Linnaeus, 1758)	Anadromous or Freshwater <sup>a</sup>	Pelagic	

n.i. — non-identifiable species.

<sup>a</sup> There are two trout subspecies in the Minho estuary, *Salmo trutta trutta* (anadromous) and *Salmo trutta fario* (freshwater resident), whose otoliths could not be distinguished.



**Fig. 3.** Relative abundance of the main prey found in cormorants' diet during the first (A) and the second wintering period (B), determined by the analysis of their pellets collected in La Vacariza night roost (Minho estuary, NW-Portugal). The number of pellets analyzed in each month was as follows: 12 (Oct-05), 35 (Nov-05), 37 (Dec-05), 33 (Jan-06), 21 (Feb-06), 13 (Mar-06), 25 (Aug-06), 24 (Sep-06), 5 (Oct-06), 4 (Nov-06), 23 (Dec-06), 0 (Jan-07), 11 (Feb-07), 17 (Mar-07).

The economically valuable *A. anguilla* (Anguillidae) was abundant in cormorants' pellets in October 2005 (RA = 0.29), but decreased in relative abundance in the following months (Fig. 3A). Despite the variations in the species composition, there were only significant changes in the RA ( $t$ -test;  $p = 0.021$ ) and FO values of Pleuronectidae ( $t$ -test;  $p = 0.036$ ) and in the RA values of Mugilidae ( $t$ -test;  $p = 0.034$ ) during the first wintering period.

In August 2006, *Echiichthys vipera* (Trachinidae) was the most abundant species identified in cormorants' pellets (RA = 0.64) (Fig. 3B), although the most frequently detected was Pleuronectidae (FO = 0.53) (Fig. 4B). In September 2006, Pleuronectidae were still a

significant prey (RA = 0.35; FO = 0.59) and *A. anguilla* was also frequent (RA = 0.16; FO = 0.47) (Figs. 3B and 4B).

During the second wintering period we did not consider November in the data analyses, because only one pellet had hard remains for identification. Pleuronectidae continued to be a primary prey, mainly in October 2006 (RA = 0.67; FO = 0.67) (Figs. 3B, 4B). The frequency of Cyprinidae and Mugilidae in the diet increased from September 2006 onwards, with the highest FO registered in December 2006 (FO = 0.50) and October 2006 (FO = 0.67), respectively (Fig. 4B).

Despite differences in cormorants' diet between wintering periods, only the abundance of Mugilidae was significantly different between years ( $t$ -test;  $p = 0.05$ ). Nevertheless, from the first to the second wintering period, Pleuronectidae and Cyprinidae decreased 37% RA, 11%FO and 5% RA, 11% FO, respectively, while Atherinidae and Mugilidae increased 13% RA, 14% FO and 29% RA, 23% FO, respectively (Figs. 3 and 4). These shifts were also detected with the SIMPER analysis, since the typifying family during the first wintering period was Pleuronectidae, while in the second wintering period Mugilidae and Cyprinidae had taken over this position (Table 2). Changes in the abundance of each prey family in the diet were the main cause for that dissimilarity (60.2) (Table 3).

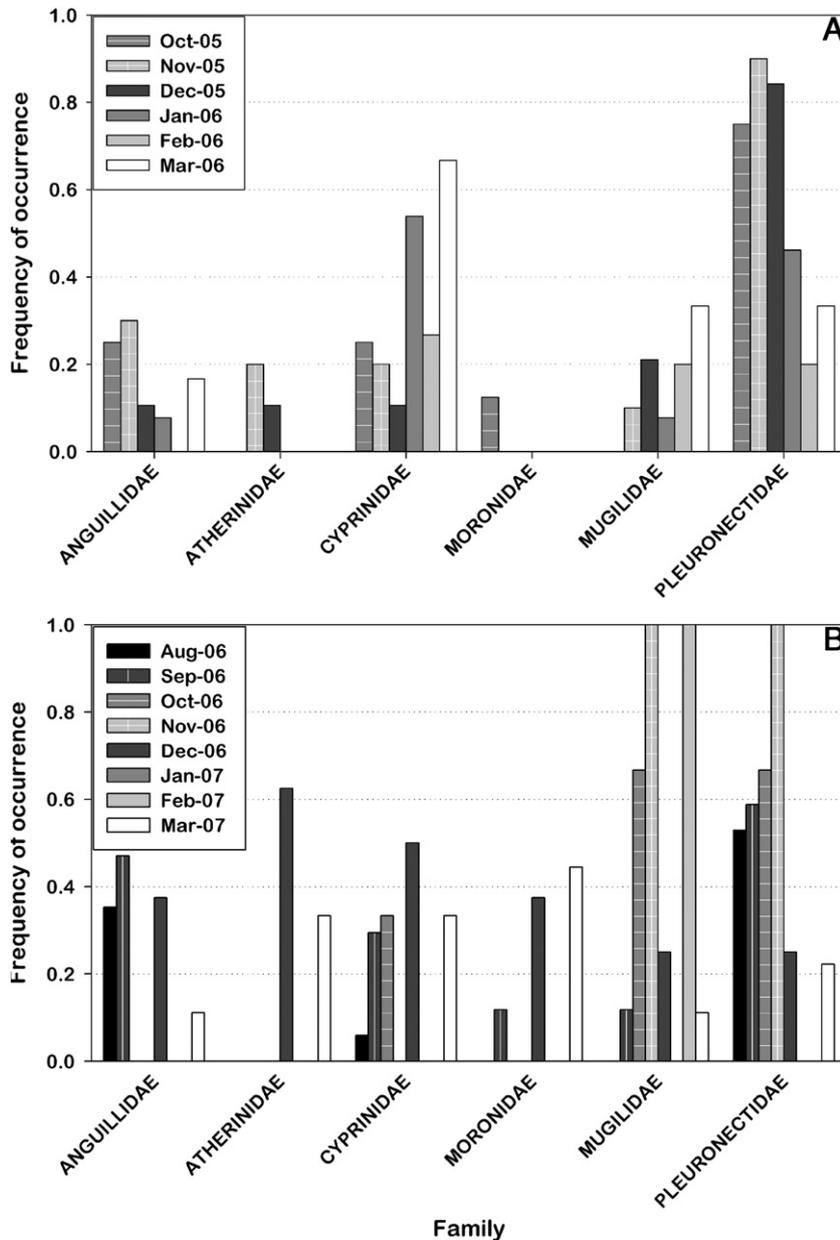
Among the analyzed factors, river discharge best explained cormorant diet over time ( $R$  global = 0.363;  $p = 0.8\%$ ; Table 4). The highest differences were detected between "low discharge" vs. "high discharge" periods ( $R = 0.479$ ;  $p = 2.9\%$ ) and "average discharge" vs. "high discharge" ( $R = 0.531$ ;  $p = 2.9\%$ ) (Table 4).

SIMPER analysis reveals that Cyprinidae and Mugilidae average contribution increases with increasing river discharge, contrary to Pleuronectidae and Trachinidae (Table 5). The families that contributed the most to the dissimilarity between the groups of discharge were Pleuronectidae and Trachinidae ("low discharge" vs. "average discharge" – diss. = 51.6), Pleuronectidae and Mugilidae ("low discharge" vs. "average discharge" – diss. = 75.1; "average discharge" vs. "high discharge" – diss. = 63.2) (Table 6).

#### 4. Discussion

In Minho estuary, most of the variation in cormorants' diet could be attributed to river discharge fluctuations. As river discharge increased, marine (e.g. Trachinidae) and marine opportunistic species (e.g. Ammodytidae, Callionymidae) disappeared from diet, while freshwater species (e.g. Cyprinidae) increased. This shift is mirrored by known seasonal and yearly variations of the local composition, abundance and distribution of estuarine ichthyofauna as a response to river discharge rates (e.g. Chícharo et al., 2006; Veiga et al., 2006). Thus, when the river discharge is high, local densities of marine and marine opportunistic species decrease (Whitfield and Harrison, 2003) while the distribution area of freshwater species increases as they move downstream with the increased flow (Veiga et al., 2006). As the studied cormorants were using a roost in the middle of the estuary, they were confronted with a changing food base over time, in accordance to variation in river discharge. The birds did not maintain a constant diet, as a result of not moving with the fish but rather taking what became locally available, notwithstanding their broad foraging range. Indeed, cormorants foraged across the entire Minho estuary, since lesser weever (*E. vipera*, Trachinidae) and cyprinids (Cyprinidae) are among cormorants' prey. Lesser weevers occur only at the river mouth and on the coast, meaning that cormorants had to fly at least 15 km downstream of their main night roost. In contrast, cyprinids are predominantly found upstream of the roost (Antunes and Rodrigues, 2004).

In the studied estuary, cormorants showed a generalist feeding strategy (following Costello, 1990), and Pleuronectidae, Mugilidae and Cyprinidae were the most common prey. Most prey were demersal and benthopelagic species, as observed in other ecosystems (e.g. Barrett et al., 1990; Carss and Ekins, 2002; Lekuona, 2002;



**Fig. 4.** Frequency of occurrence of the main prey found in cormorants' diet during the first (A) and the second wintering period (B), determined by the analysis of their pellets collected in La Vacariza night roost (Minho estuary, NW-Portugal). The number of pellets analyzed in each month was as follows: 12 (Oct-05), 35 (Nov-05), 37 (Dec-05), 33 (Jan-06), 21 (Feb-06), 13 (Mar-06), 25 (Aug-06), 24 (Sep-06), 5 (Oct-06), 4 (Nov-06), 23 (Dec-06), 0 (Jan-07), 11 (Feb-07), 17 (Mar-07).

Leopold et al., 1998; Suter, 1997). Cormorants also showed a high feeding plasticity, since they fed on pelagic (e.g. *Atherina* sp., *Liza* sp.), semipelagic (e.g. *Cyprinus carpio*, *Gobio lozanoi*) and demersal fishes (e.g. *P. flesus*). The generalist feeding strategy and high feeding plasticity are characteristics shared by many cormorant species in various

ecosystems (e.g. Barquete et al., 2008; Campos et al., 1993; Humphries et al., 1992; Trayler et al., 1989).

Since cormorants are both generalistic and opportunistic piscivorous predators, exhibiting a high feeding plasticity, they may be considered good local samplers of ichthyofauna. The double-crested

**Table 2**

Typifying families of *Phalacrocorax carbo* diet during the coincident months of the first (2005–2006) and second (2006–2007) wintering periods, which were determined with prey abundance data and using SIMPER analysis.

Factor – wintering	Family	Avg. sim.	Sim./st. dev.	Contr. %
1st wintering (Avg. sim. – 53.6)	Pleuronectidae	33.0	3.5	61.6
	Cyprinidae	14.0	0.9	26.2
	Mugilidae	3.5	0.9	6.5
2nd wintering (Avg. sim. – 40.7)	Mugilidae	18.7	2.5	46.0
	Cyprinidae	13.1	3.3	32.2
	Pleuronectidae	5.1	1.0	12.6

**Table 3**

Discriminating families of *Phalacrocorax carbo* diet during the coincident months of the first (2005–2006) and second (2006–2007) wintering periods, which were determined with prey abundance data and using SIMPER analysis.

Factor – wintering	Family	Avg. diss.	Diss./st. dev.	Contr. %
1st vs 2nd (Avg. diss. – 60.2)	Pleuronectidae	16.7	1.8	27.8
	Mugilidae	14.4	1.2	24.0
	Cyprinidae	9.1	1.6	15.1
	Atherinidae	9.1	0.8	15.1
	Anguillidae	4.3	0.8	7.1
	Gadidae	1.6	0.9	2.7

**Table 4**

R-statistic values and their significance values (*p*) for pair-wise comparisons of *Phalacrocorax carbo* prey abundance using ANOSIM analysis, for differences between river discharge levels (low, average, high), seasons (summer, autumn, winter) and wintering periods (1st – 2005–2006, 2nd – 2006–2007).

Factor	Interaction	R	<i>p</i> (%)
River discharge Global R: 0.363 ( <i>p</i> = 0.8%)	Low vs Average	0.146	17.1
	Low vs High	0.479	2.9
	Average vs High	0.531	2.9
Season Global R: 0.249 ( <i>p</i> = 5.5%)	Summer vs Autumn	0.382	14.3
	Summer vs Winter	0.364	19.0
	Autumn vs Winter	0.140	12.7
Wintering Global R: 0.125 ( <i>p</i> = 22.9%)	1st vs 2nd	0.260	14.3

cormorants (*Phalacrocorax auritus*) present in the Gulf and Estuary of the St. Lawrence River were also suggested to be excellent samplers of marine resources, since the analyses of their diet revealed variations in the stock of coastal species, such as capelin *Mallotus villosus* and sand lance *Ammodytes* sp. (Rail and Chapdelaine, 1998).

In Minho estuary, it seems that cormorants do not need to move with a preferred resource; instead they are able to live on any fish species available. Thus, we also suggest that temporal variations in the local ichthyofauna can be followed by analyzing great cormorant diet. The use of bird diet as an indicator of ecosystem changes has repeatedly been proposed to monitor ecosystem change (e.g. Davoren and Montevecchi, 2003; Litzow et al., 2000; Montevecchi et al., 1988) and the main advantage is the possibility to evaluate the fundamental environmental conditions without having to capture the full complexity of the system. The establishment of a link between changes of cormorant diet and river inflow would be particular relevant for ecohydrologists, since they are permanently seeking for indicators that relatively easily demonstrate shifts caused by hydrology in the ecosystem (Morais et al., 2012).

Although we consider that great cormorants are good samplers of local ichthyofauna, we think that our interpretations could be further enhanced by adding data on cormorant distribution and foraging behavior along the Minho estuary using, for example, telemetry analysis (Anderson et al., 2004) and ichthyofauna surveys. Nonetheless, cormorant pellet analysis alone provides a robust, simple and cheap mean to follow birds' diet and ichthyofauna state parameters, on the scale of an entire estuary.

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**Table 5**

Typifying families of *Phalacrocorax carbo* diet for the different levels of river discharge (low, average, high) previously defined with a cluster analysis (data not shown), which were determined with prey abundance data and using SIMPER analysis.

Group	Family	Avg. sim.	Sim./st. dev.	Contr. %
Low river inflow (Avg. sim. – 51.9)	Pleuronectidae	27.4	1.8	52.7
	Anguillidae	15.5	13.0	29.8
	Trachinidae	4.9	0.4	9.4
Average river inflow (Avg. sim. – 63.5)	Pleuronectidae	50.8	2.9	80.0
	Cyprinidae	7.5	1.3	11.8
High river inflow (Avg. sim. – 44.2)	Cyprinidae	19.2	2.0	43.4
	Mugilidae	13.6	1.6	30.7
	Pleuronectidae	5.1	1.0	11.6
	Atherinidae	2.8	0.6	6.4

**Table 6**

Discriminating families of *Phalacrocorax carbo* diet for the different levels of river discharge (low, average, high) previously defined with a cluster analysis (data not shown), which were determined with prey abundance data and using SIMPER analysis.

River inflow	Family	Avg. diss.	Diss./std. dev.	Contr. %
Low vs Average (Avg. diss. – 51.6)	Pleuronectidae	13.5	1.4	26.2
	Trachinidae	11.6	0.9	22.5
	Anguillidae	9.2	3.0	17.7
	Cyprinidae	7.1	1.0	13.8
	Mugilidae	4.2	1.1	8.1
	Soleidae	1.4	0.9	2.7
Low vs High (Avg. diss. – 75.1)	Pleuronectidae	16.1	1.5	21.4
	Mugilidae	14.8	1.1	19.7
	Trachinidae	11.6	0.9	15.4
	Cyprinidae	10.8	1.6	14.3
	Atherinidae	9.1	0.8	12.1
	Anguillidae	7.9	2.5	10.5
Average vs High (Avg. diss. – 63.2)	Pleuronectidae	25.1	2.5	39.7
	Mugilidae	12.3	1.0	19.5
	Atherinidae	9.1	0.8	14.4
	Cyprinidae	9.1	1.4	14.4
	Anguillidae	1.5	1.8	2.4

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