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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.

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^2, 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^2, 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 $m^3\ s^{-1}$ (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 Eerden, 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 constrains.

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 Härkonën (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