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RESEARCH ARTICLE

Diet of *Phalacrocorax carbo sinensis* (Aves, Phalacrocoracidae) and impact on fish stocks: a study case in Cabras and Mistras lagoons (Sardinia, Italy).

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Abstract

1 - The work aims to study the feeding habits of *Phalacrocorax carbo sinensis* wintering in the Cabras and Mistras lagoons and to assess the impact of the cormorants colony on fish stocks.

2 - 438 bird flocks of Great Cormorant (*Phalacrocorax carbo sinensis*) wintering in the Cabras and Mistras lagoons (central-western Sardinia) (SPA ITB034008 and ITB034006 respectively) were analysed.

3 - Through the morphological analysis of undigested hard body parts, such as otoliths, it was possible to trace to the preyed species and their biomass and, then, to the average daily consumption of cormorants.

4 - The trophic spectrum was dominated almost exclusively by euryhaline, gregarious fish species. Mugilidae, and particularly *Liza ramada* with a percentage index of relative importance (%IRI) of 75.28 and *L. saliens* (%IRI = 17.78) were the most important preys, while *Dicentrarchus labrax* (%IRI = 3.53) was of secondary importance. Other species, as *Diplodus vulgaris* (%IRI = 0.06), *Sparus aurata* (%IRI = 0.01), *Solea solea* (%IRI = 0.04) and *Anguilla anguilla* (%IRI = 0.01), completed the diet.

5 - The Daily Food Intake (DFI) was estimated in 478.4 ± 18 g/day. The overall amount of biomass preyed by the cormorants during the entire wintering season was calculated in about 422 tons. Considering the Cabras lagoon area, it was possible to estimate an amount of fish taken equal to 189.4 Kg/ha during the same period.

Keywords: Cabras lagoon, *Phalacrocorax carbo sinensis*, bird flock, diet, otoliths, daily food intake.

Introduction

The Great Cormorant, *Phalacrocorax carbo sinensis* (Blumenbach, 1798), is a highly specialized ichthyophagous bird, adapted to consume large meals (Carss, 2003). This species is able to cover great distances in order to exploit fishing areas far from the reproduction sites (Cramp and Simmons, 1977). These waterfowl nest in the northern districts of the Western Palearctic, and play a short migration to reach the wintering areas which are located mainly along the Mediterranean coast. The species has been nearly extinct due to persecution in the 19th and first half of 20th century (Van Eerden and Gregersen, 1995). Following near extinction, in the last few decades in northern European regions an implementation of the protection measures was established (EU Bird Directive 79/409/EEC; 97/49/EEC). As a consequence a rapid increase in the population abundance have been recorded in the wintering areas such as the Mediterranean area (Carss, 2003; Volponi and Addis, 2003).

The growth of the cormorants number near the productive transitional waters is matter of great concern among fishermen, who consider the cormorant to be a competitor for fisheries. The conflict between fishery practitioners and bird conservation plans increased during the time (Heinimaa, 2007; Vetemaa *et al.*, 2010).

This problem is particularly acute in Sardinia (Addis and Cau, 1997). The island represents, in fact, a favourable wintering area for many waterfowl, as a consequence of its peculiar environmental characteristics, and hosts one of the largest populations of *Phalacrocorax carbo sinensis* in the Mediterranean basin (Baccetti, 1988).

In this context, the Cabras and Mistras lagoons represent about the 30% of all the transitional waters of the entire Sardinian territory. Moreover, the lagoon has a great value for its role as spawning and nursery areas for many species of commercial interest (Cucco *et al.*, 2012) and represent one the most productive for fisheries in Sardinia (Cannas *et al.*, 1997; Murenu *et al.*, 2004).

In these areas the maximum number of cormorants is usually recorded between November and December (Volponi and Addis, 2003; Alea Ricerca and Ambiente, 2011). The peak was observed in the mid 1990's with a population of 13,685–15,500 birds (Volponi and Addis, 2003). Consequently during the wintering season 1994-1996, the local administration started a control plan in order to reduce cormorant numbers (disturbance and shooting at roosts and feeding areas) (Schenk, 1997). Even though after 1996 the cormorant population wintering in the Oristano area has decreased dramatically, it recently returned to the levels of the first 90's (Volponi and Addis, 2003). Based on the mid-January census carried out in 2011, the individuals amounted to around 13,000 (Alea Ricerca and Ambiente, 2011).

Although the problem should be considered at pan-european level, nowadays an European cormorants control policy is still lacking (Heinimaa, 2007). Actually, in some Sardinian transitional waters, monitoring and management plans are applied (Alea Ricerca and Ambiente, 2011). Particularly, together with daytime waterfowl censuses, diet studies are still very important in order to assess the real impact on the fisheries and to establish effective management measures. Despite the species is receiving considerable attention, very few studies concerning the diet of the species in the area have been published (Addis *et al.*, 1995; Addis and Cau, 1997). This work focused on the feeding habits of the *Phalacrocorax carbo sinensis* colony wintering in the complex of the Cabras and Mistras Lagoons and aimed to assess the composition of the preyed species and the impact of bird predation on the fisheries of these productive lagoons.

Materials and methods

Study Area

The study was conducted in the complex of the Cabras and Mistras Lagoons (Sardinia, Italy) located in the northern sector of the wide Gulf of Oristano (39°57'N 08°29'E; 39°54'N 08°27'E for Cabras and Mistras respectively) (Fig.1).

Cabras Lagoon is one of the main brackish systems (about 2228 ha) of the western Mediterranean Sea. The basin receives a supply of fresh waters by means of two tributaries, the Rio Mare Foghe in the northern part and the Rio Tanui in the southern part. The main depth is about 1.7 m, with a tidal amplitude of about 20 cm (Cucco *et al*., 2012).

Mistras Lagoon is a marine-hyperhaline system (450 ha), characterised by the absence of fresh water input from rivers. The water exchange with the sea is mainly due to microtidal variations (Tigny *et al*., 2007; Magni *et al*., 2008).

Both areas are designated as Special Protection Areas (European Commission Birds Directive 79/409/EEC) (SPA ITB034008; ITB034006) and Site of Community Importance (European Commission Habits Directive 92/43/EEC) (SCI ITB030036; ITB030034). Cormorants establish their colony as a roosting site in four small islands located in the north-eastern sector of the Mistras Lagoon, whereas they use the Cabras Lagoon as a feeding area. The feeding activity starts just after sunrise, when cormorants leave the dormitories to the foraging sites and ends at sunset, when the individuals move back to the roosts (Fig. 1).

Diet Analysis

A total of 438 bird flocks were collected once a month from the dormitory of Mistras (Fig. 1) between October 2010 and March 2011. The material was fixed in a solution of 20% alcohol for the subsequent analysis. Samples were studied according to Duffy

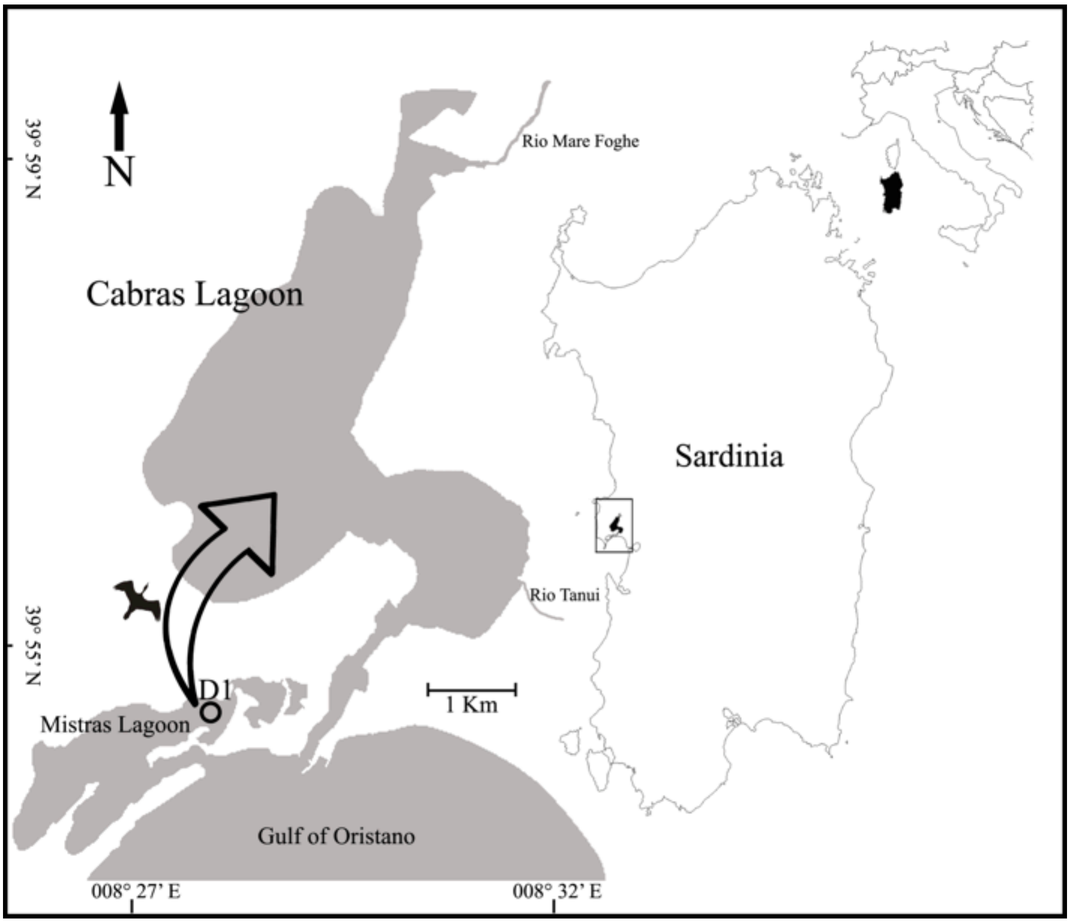

Figure 1. Map of the studied area. The arrow indicates the cormorants movement from the main dormitory (D1) to the feeding zone.

and Laurenson (1983). The superficial layer of mucus was dissolved in hot water. Each sample was then washed repeatedly with distilled water on a series of 3 sieves in descending mesh (2.0 mm, 500 µm, 250 µm, Endecotts Ltd, England). The three obtained fractions were examined using a stereomicroscope. The hard parts, such as bony fragments and, particularly, otoliths allowed the prey identification.

Otoliths were determined by the use of the Aforo database (Shape Analysis of Fish Otoliths, http://www.cmima.csic.es/aforo) (Harkonen, 1986; Costa, 2003), and then photographed and measured. Otolith Length (OL, mm), Width (WL, mm) and Weight (OW, g) were registered. Otoliths for which it was not possible to determine the belonging taxon were categorized as N.I. (not identified) and not included in the data analysis. The obtained data allowed to estimate the size and the biomass of the fish preyed through the use of biometric relationships, according to Volponi (1994) and Harkonen (1986) (Table 1):

$$FW = a * OL^b$$

where FW is the Fish Weight, OL is the Otolith Length, (*a*) is the intercept of the relationship and (*b*) is the slope of the relationship.

For each prey category the average weight (AW, g), standard deviation as well as the maximum (W_{max}) and minimum (W_{min}) values of weight were calculated. While for the species for which it was not possible to apply the formulas, mean values of body mass (AW, g) were used, according to Cherubini (1996) and Mantovani (1997). Particularly, for *Diplodus vulgaris* AW = 30 g (Mantovani, 1997), for Atherinidae AW = 5 g (Cherubini, 1996), for Gobiidae AW = 20 g (Cherubini, 1996).

Data collected were analysed both by numerical (Lagardère, 1975) and by ponderal analysis (Lauzanne, 1982).

Percent frequency of occurrence (%FO), percent number (%N), percent weight (%W) and the vacuity coefficient (%Cv) were calculated in order to describe the diet. According to the %N values, prey items were grouped into three categories (%N> 50 dominant prey; 10 <%N <50 secondary prey; %N <10 accidental prey) (N'Da, 1992).

The quantitative importance of each prey group in the diet was also evaluated, through the index of relative importance (IRI) (Carrassòn *et al.*, 1997):

$$IRI = (\%W + \%N) * \%FO$$

where %W is the average percent weight, %N is the average percent number and %FO is the percent Frequency of Occurrence.

The percentage IRI value of each prey with respect to the total value (Cortés, 1997), was evaluated using the formula:

Table 1 - Parameters of the Otolith Length-Fish Weight relationship for the preyed categories (*a* = Intercept of the relationship; *b* = Slope of the relationship).

Family/Species	a	b	Author
Mugilidae	0.047	4.127	Volponi, 1994
Moronidae	0.051	3.817	Volponi, 1994
Soleidae	2.535	3.444	Harkonen, 1986
Sparus aurata	0.296	3.447	Volponi, 1994
Anguillidae	4.052	3.721	Harkonen, 1986

$$\%IRI = \frac{IRI_{ij}}{\sum_i IRI_{ij}} * 100$$

where IRI_{ij} is the absolute IRI value of the prey *j* in the diet of the species *i*.

Cumulative prey curves (Ferry and Cailliet, 1996) were computed with EstimateS software (Version 8.2 R.K. Colwell, http://purl.oclc.org/estimates), in order to assess whether the number of the sample was sufficient to describe the diet. The slope of the linear regression (*b*) through the ultimate five subsample was used, where $b \leq 0.05$ signified acceptable levelling off of the prey curve for diet characterization (Brown et al., 2012) (Fig. 2).

The breadth of the trophic niche was determined by the use of the indexes of Levins (B_i) (Levins, 1968) and Shannon-Weaver (H') (Shannon and Weaver, 1949):

$$B_i = \frac{1}{n-1} * \frac{1}{\sum_j p_{ij}^2 - 1}$$

where B_i is the Levins measure of niche breadth and p_{ij} is the proportion of the prey *j* in the diet of the species *i*,

$$H' = -\sum_{i=1}^{s} p_{ij} * \log_e * p_{ij}$$

The value of the average daily consumption (Daily Food Intake, DFI) was evaluate as the mean fish mass per pellet (Keller, 1995). The DFI was compared to the number of feeding individuals counted in the lagoon between October 2010 and March 2011 (Alea Ricerca and Ambiente, 2011). Since cormorants normally produce a bird flock each day, independently to the number of meals (Zijlstra and Van Eerden, 1995), we assume that the average biomass content in a flock corresponds to the cormorant average daily consumption. The total biomass preyed was calculated on a monthly basis. This was achieved by multiplying the estimated number of cormorants foraging in the Cabras Lagoon each month (Alea Ricerca and Ambiente, 2011) with the average daily food intake. Finally, the obtained values were summed in order to calculate the total biomass of fish consumed by cormorants in the wintering season.

Results

Of the 438 bird flocks collected, 81 consisted only of a casing of mucus (%Cv = 22). The cumulative prey curve generated for the data reached a linear slope of $b = 0$ for the ultimate five subsamples of the dataset (n = 357) (Fig. 2).

P. carbo sinensis showed a limited trophic

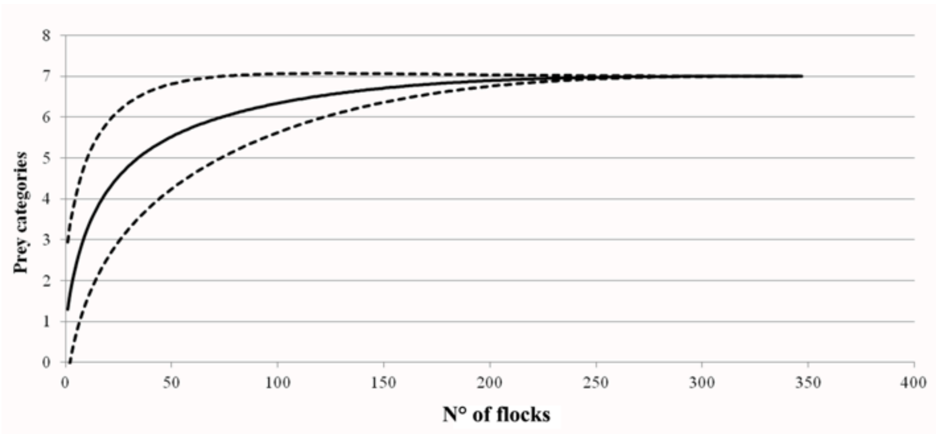

Figure 2. Cumulative number of prey categories (solid line) and 95% CIs (dashed lines) for the diet of *P. carbo sinensis* during the wintering season 2010-2011.

spectrum, as indicated by the low values of the indexes of Levin (B_i) and Shannon (H') (0.05 and 0.69, respectively).The diet was composed almost exclusively of Osteichthyes. In the 357 full bird flocks, a total of 3,920 otoliths were found. Only 262 were broken or worn and were considered as not identified. This small number did not influenced the analysis. Through the analysis of the remaining 3,658 it was possible to identify 1,890 individuals, belonging to eleven species (Table 2).

The most important prey was the Mugilidae *Liza ramada* (%N = 55.80; %IRI = 75.28), while *L. saliens* (%N = 21.32; %IRI = 17.78) was considered as secondary (Table 3).

Another Mugilidae, *L. aurata* (%IRI = 2.92), and the Moronidae *Dicentrarchus labrax* (%IRI = 3.53) were prey items of minor importance (Table 3). The remaining species registered in the diet, with very low values of abundance, were classified as accidental preys (Table 3).

The small fraction of remains of insects, molluscs and plants were considered to derive from accidental ingestion or from the diet of the fish preyed.

The value of the Daily Food Intake (DFI) was equal to 478.4 ± 18 g/day (mean ± SE) per individual. Cormorants are present in Sardinia from autumn to early spring. During the time of the study the lowest number of feeding individuals in the Cabras lagoon was registered in October, while the maximum peak was noticed in December (Alea Ricerca and Ambiente, 2011). During this month was estimated a total of 143 tons of fish preyed (Table 4).

The overall biomass gathered during the entire wintering season, from October to March was estimated in about 422 ± 20 t (mean ± SE). Considering the ponderal composition of the diet (%W) (Table 3), the amount of fish stock consumed during the season consisted of

Table 2. Descriptive statistics for the preyed species (N = Number of Preys; AW = Average Weight and relative Standard Deviation; Wmin = Minimum Weight; Wmax = Maximum Weight).

Family	Species	N	AW (g)	W_{min} (g)	W_{max} (g)
Mugilidae	*Liza ramada*	1055	86.21 ± 52.02	1.83	375.15
	Liza saliens	403	86.73 ± 61.31	3.12	507.33
	Liza aurata	131	97.82 ± 6761	11.63	498.57
	Mugil cephalus	39	76.58 ± 42.89	12.46	150.52
Moronidae	*Dicentrarchus labrax*	134	144.81 ± 87.24	7.75	398.71
Atherinidae	*Atherina boyeri*	51	5	5	5
Sparidae	*Diplodus vulgaris*	50	30	30	30
	Sparus aurata	2	120.74 ± 139.32	22.26	219.22
Soleidae	*Solea solea*	14	149.42 ± 112.08	20.72	388.25
Anguillidae	*Anguilla anguilla*	6	199.73 ± 135.56	57.53	442.51
Gobidae	*Gobius niger*	5	20	20	20

Table 3. Diet of *P. carbo sinensis* in the Cabras lagoon (N = Number of Preys; %FO = Percent Frequency of Occurrence; %N = Percent Number; %W = Percent Weight; %IRI = Percent Index of Relative Importance).

Species	N	%FO	%N	%W	%IRI
Liza ramada	1055	67.79	55.82	54.55	75.28
Liza saliens	403	41.74	21.32	18.30	17.78
Liza aurata	131	19.89	6.93	6.71	2.92
Mugil cephalus	39	6.16	2.06	1.56	0.24
Dicentrarchus labrax	134	19.05	7.09	10.16	3.53
Atherina boyeri	51	4.20	2.70	0.13	0.13
Diplodus vulgaris	50	1.96	2.65	0.13	0.06
Sparus aurata	2	0.56	0.11	0.79	0.01
Solea solea	14	2.24	0.74	1.10	0.04
Anguilla anguilla	6	1.12	0.32	0.63	0.01
Gobius niger	5	0.28	0.26	0.05	0.00

230 t of *L. ramada*, 89 t of L. saliens, 33 t of *L. aurata*, 8 t of M. cephalus, 49 t of *D. labrax*, while the overall weight of the remaining species found amounted in 13 t.

Discussion

The transitional waters of the western Sardinia island are one of the most important wintering areas in the Mediterranean basin

Table 4. Table 4. Biomass of fish consumed by cormorants foraging at Cabras Lagoon during the wintering season.

Months	N Cormorants/day	Kg/day	Kg/month	t/month
October	85	40.63	1,259.53	1
November	4753	2,271.93	68,158.02	68
December	9637	4,606.49	142,801.07	143
January	2890	13,81.42	42,824.02	43
February	8011	3,829.26	107,219.22	107
March	4040	1,931.12	59,864.72	60
TOTAL		14,060.85	42,2126.58	422

(Van Eerden and Munsterman, 1995). According to results from last census (2010-2011) the wetlands of Oristano area hosted a total of 53,484 cormorants counted from October to March. The peak was observed in the mid January with a population of 13,091 (Fig. 3), 91.5% (11,976 individuals) of which in the only Mistras lagoon (Alea Ricerca and Ambiente, 2011). Cormorants establish their colony as a roosting site in the Mistras lagoon, whereas they use the more productive Cabras Lagoon as a feeding area.

The diet of the Great Cormorant was investigated through the analysis of the bird flocks produced one per day, usually during the hours of rest (Cherubini and Mantovani, 1997), which contain the remains of fish consumed (Veldkamp, 1995). The narrow niche breadth (B_i) was linked to the abundance and the behaviour of the main fish species present in the Lagoon.

The trophic spectrum was dominated almost exclusively by euryhaline fish species, particularly those belonging to the family Mugilidae, such as *L. ramada*, *L. saliens*, *L. aurata*, as stated also in previous works carried out in the coastal wetlands of the central western (Addis and Cau, 1997; Mantovani, 1997), south-western Sardinia (Cau *et al.*, 2010; 2011) and in the North Adriatic (Privileggi, 2003).

Moreover, among the other fish species preyed by the cormorants, sea bass *D. labrax*, sea bream *S. aurata* and common two-banded sea bream *D. vulgaris* were considered as preys of minor importance.

Since cormorants normally produce a bird flock each day, independently to the number of meals (Zijlstra and Van Eerden, 1995), it can be stated that the average biomass content in a flock corresponds to the cormorant average daily consumption. In general, the daily food intake is related to the sex and the age of the individuals (body mass), to their life cycle stage and to their geographical area. The quantity of preyed fish is higher at low temperatures (Veldkamp, 1997): Grémillet et al., (2003) reported a DFI value of 672 g/day for *P. carbo* wintering in Scotland, while previously Carss *et al.*, (1997) and Grémillet (1997) predicted values up to 800 g/day. In a study conducted on a similar species, *P. aristotelis*, in the east Scotland Wanless *et al.*, (1993) stated that, during incubation the

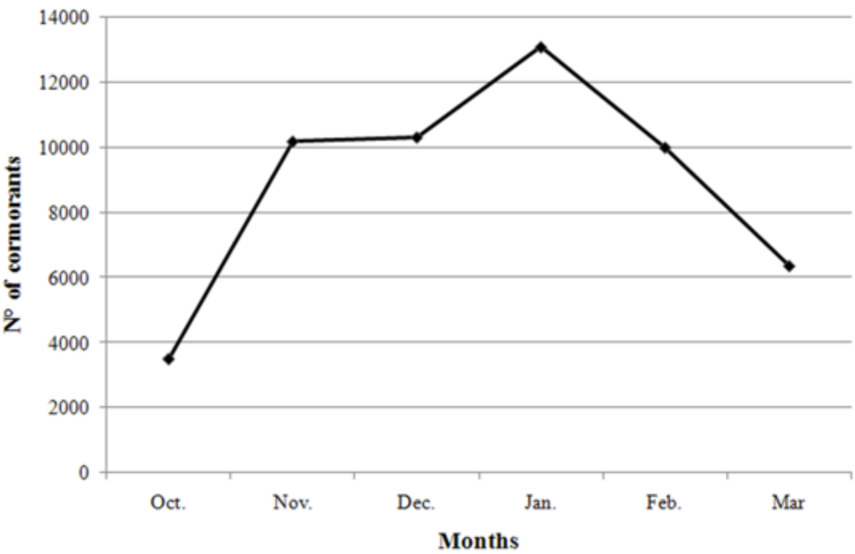

Figure 3. Number of cormorants feeding in the Cabras Lagoon during the wintering season 2010-2011 (Alea Ricerca and Ambiente, 2011).

average daily requirement is 389 g of fish, while a bird with three chicks required about 920 g.

Our analysis led us to consider a DFI value equal to 478.4 ± 18 g/day (mean ± SE). This result seems in agreement with the studies of other authors carried out at similar latitudes. Privileggi (2003) reported an average consumption of 450 g/day of fish for the cormorants wintering in the Grado lagoon (North Adriatic), while Volponi (1997) predicted a slightly lower value, equal to 343 g/day for *P. carbo* sinensis in the Po Delta.

Our findings differed slightly from those reported in a previous study carried out in some wetlands of the central western Sardinia on stomach contents (DFI = 300 g/day) (Addis and Cau, 1997). The higher value evidenced from our analysis may be attributable to the different methodology used.

The overall amount of biomass consumed in the Cabras Lagoon in the wintering season (October to March), was estimated to be around 422 ± 20 tons. Considering that the lagoon covers an area of about 2,228 ha, we can assume a consumption of 189.4 Kg/ha of fish for the 2010/2011 wintering season.

Conclusions

The study showed how the Great Cormorant is an opportunistic, fish eating species. The diet was composed almost exclusively of a relatively limited number of species. It can generally be stated that it reflects the composition of the ichthyological communities inhabiting the Cabras Lagoon. The high abundance of species such as those belonging to the Mugilidae family, joined to their typical gregarious behaviour (traveling in schools), could increase the predatory success of the cormorants, which, furthermore developed a social feeding strategy (Hughes et al., 1999). The large fish crowds could also be more easily identifiable by the birds during the flight (Wittenberger and Hunt, 1985), which would be followed by other individuals to the feeding areas (Burger, 1997).

Future studies should involve the fishery practitioners in order to define more in detail the economical impact of this species on fisheries. These kind of studies could be useful to elaborate integrated management and protection plans, taking into account the productive needs of these important transitional waters.

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