Does the Common Kingfisher (*Alcedo atthis*) select the most energetic fish prey?

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During the chick-rearing period, strategies of prey provisioning can have a decisive impact on several reproductive aspects. Adults can maximise their foraging effort by increasing the number of fish-prey brought to the nest per unit time and/or by catching more energetic prey, i.e. larger prey or prey with relatively higher caloric values. The Common Kingfisher (*Alcedo atthis*) is a fish-eating predator normally breeding in freshwater habitats. We collected data on fish-prey proportions found at nests ($n = 10$) and determined the caloric content of such fish-prey (6 species overall) in rivers in northern Iberia. The proportion of each fish-prey species in the nest was not correlated with the proportion of lipids, proteins or carbohydrates, nor with its caloric content. Furthermore, the most energetic prey was not the most commonly consumed, illustrating the fact that the Common Kingfisher does not fish for the most energetic prey during the chick-rearing period.

1. Introduction

Understanding the foraging strategy of fish-eating predators has not only biological and ecological importance (Stewart *et al.* 1997, Grémillet *et al.* 1998, Miranda *et al.* 2006), but is also relevant for the conservation and management of aquatic ecosystems overall (Stewart *et al.* 2005, Wanless *et al.* 2005, Ramos *et al.* 2009).

During the chick-rearing period, strategies of prey provisioning and particularly the type and amount of fish-prey provided to the chicks per unit time can have a decisive impact on several reproductive aspects such as chicks' survival and growth rate (Barrett *et al.* 1987, Monaghan *et al.* 1989, Wanless *et al.* 2005, Paiva *et al.* 2006, see also for a specific work on Kingfishers Čech &

Čech 2017). Adults adjust their effort to broods size (Čech & Čech 2017) by carrying more food (i.e. by increasing the number of fish-prey provided to the nest per unit time), though they could also maximize such an effort by catching more energetic prey, i.e. larger prey or prey with relatively higher caloric values (Golet *et al.* 2000, Stienen *et al.* 2000, Litzow *et al.* 2002, Wanless *et al.* 2005). This last question, however, is a less well known issue, especially in freshwater avian predators.

The Common Kingfisher *Alcedo atthis* (hereafter, Kingfisher) is a fish-eating specialized predator which feeds its chicks with unique prey deliveries (Cramp 1985). The Kingfisher's diet has been analyzed in several studies (e.g., Iribarren & Nevado 1982, Reynolds & Hinge 1996, Campos *et al.* 2000, Isotti & Consiglio 2002, Čech & Čech
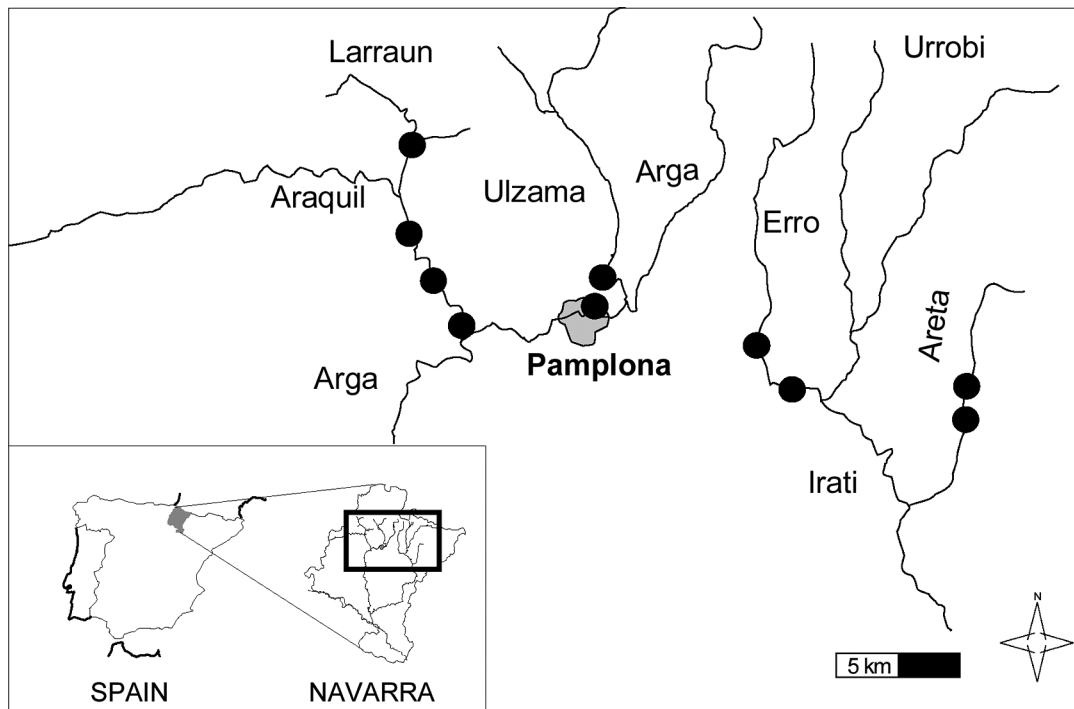
Fig. 1. Locations of the sampling points (nests) where the study was carried out in Navarra, Spain.

2015). Most of these cited studies have focused on prey-size selection, but much less attention has been paid to selection of fish-prey in relation to their caloric content. The majority of the studies that have dealt with fish energetic content estimates have focused on marine environments (Lawson *et al.* 1998, Anthony *et al.* 2000, Wanless *et al.* 2005). By contrast, very few have considered freshwater ecosystems (but see Elliott 1976, Draulans 1988, Schreckenbach *et al.* 2001, Johnson *et al.* 2017), especially in southern Europe, where still a considerable break of knowledge is found as compared to northern Europe or America.

The aims of this study were (1) to analyse the caloric content of a number of freshwater fish commonly consumed by Kingfishers in Iberia, and (2) to test whether this species may select the most energetic prey or, alternatively, may prey upon the most common fish prey.

2. Material and methods

Field work consisted of identifying the fish-prey consumed by breeding Kingfishers (by pellet analysis), and determining the fish-prey availability in the river, along with its caloric content. Pellets were collected from 10 nests found in six rivers of similar ecological features within the region of Navarra (northern Iberia; Fig. 1). The study was carried out from 2007 to 2009, and the number of sampling nests per river were: Araquil (3 in 2007); Ulzama (1 in 2007); Larraun (1 in 2007); Areta (1 in 2007, 1 in 2008); Erro (1 in 2007, 1 in 2008); Arga (1 in 2009). The Kingfishers' breeding density range between <0.01 nest/ km (Arga) to 0.20 nest/km (Araquil), with a mean estimation of 0.06 nest/km (for further details see Vilches *et al.* 2012).

We searched for nests by means of river transects conducted during the Kingfisher breeding period, March/April to August, from 2007 to 2009. Specifically, we looked for river banks where there was a hole being used by a breeding pair. The species breeding density in the region was rather low (Vilches *et al.* 2012), and the distance from one territory to the next was commonly >5 km. Nest-selection (from all of the nests found) was carried out in order to reduce pseudo-replication, either caused by sampling a same breeding pair within a year [second broods are common
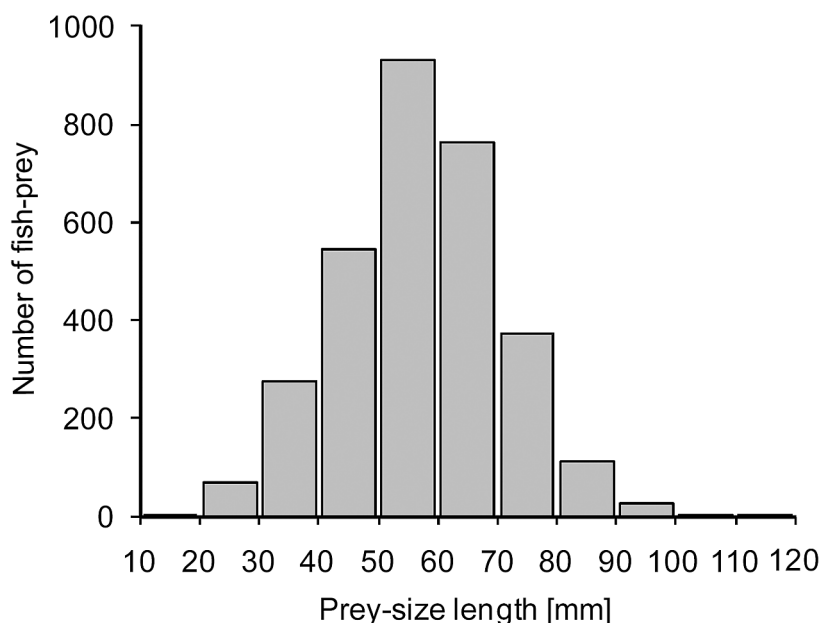
Fig. 2. Total length distribution of fish-prey species found at nests (n = 3,099).

within the region and they are commonly raised at nests sited close (<500 m) to each other; A. Vilches, pers. obs.] or from one year to the next. Accordingly, active nests detected close to a nest already used in a same breeding season or at the same site and/or close to a site occupied in previous years were excluded.

Pellets were taken from each nest with a 1 m-long, hand-made rake at the end of the breeding season, once the chicks had left the nest (i.e., from September to November). Pellets were dissected in the laboratory and the diagnostic bone pieces were extracted in order to identify the fish-prey and assess their length (Reynolds & Hinge 1996, Miranda & Escala 2002, Čech & Čech 2015). The proportion of each fish-prey in the nests was calculated (1) over the entire sample and (2) over those nests where that particular fish species was detected. This proportion was calculated after pairing bones with diagnostic value, which were: pharyngeal bone (used for the identification of cyprinids), maxillae (used for salmonids) (Miranda & Escala 2002).

Apart from pellet collection, and with the aim of sampling fish-prey availability in the river and calculating the species caloric content, we obtained a sample of those fish-prey found in the nests using the electrofishing method (Reid *et al.* 2009).

Electrofishing surveys were carried out following the procedures set out in CEN standard EN 14011 and with the corresponding authorisations (Government of Navarra). Electrofishing was carried out at a total of three sampling points situated at 500 m upstream from the nest, 500 m downstream, and at the site where the nest was found. This work was conducted from June to August, when nests were still being used by the breeding pairs, thus ensuring that fish-prey samples were collected in a period when Kingfishers were also foraging in the area and also minimizing any possible seasonal variations in the caloric content and community structure of fish-prey (Campos *et al.* 1997, Lawson *et al.* 1998).

Once captured, all fish-prey were placed in receipts containing fresh water with anaesthetic (2-Phenoxyethanol, 0.5 ml/l), and were thereafter individually identified, measured (total length ± 1 mm; from the tip of the snout to the end of the longer lobe of the caudal fin) and released (for further details see Leunda *et al.* 2006). A subsample of the species captured (n = 99; for details see Table 1) was frozen for the caloric content analyses that were carried out in Laboratorios LAIA Inc. The fish-prey retained for caloric content analyses were all 40 to 80 mm in total length, corresponding to the range for the majority (84.4%) of fish-prey found at the nests (Fig. 2). After catching their prey

Table 1. Proportion of lipids, proteins and carbohydrates and body mass-standardized caloric content of each fish-prey species (mean ± 95% CI). Values with the same letter are those between which no signifi-cant differences were detected according to a Tukey-B *a posteriori* test.

	N	Lipids [%]		Proteins [%]		Carbohydrates [%]		Caloric Content [KJ/g]	
Ebro Barbel	19	3.6 ± 0.4	b	16.6 ± 0.7	ab	1.0 ± 0.2	a	2.3 ± 0.1	a
Bermejuela	15	6.0 ± 0.6	a	16.7 ± 0.5	ab	1.6 ± 0.4	a	3.2 ± 0.2	b
Pyrenean Minnow	17	3.4 ± 0.5	b	17.4 ± 0.6	b	1.2 ± 0.2	a	2.3 ± 0.2	a
Pyrenean Gudgeon	15	2.7 ± 0.8	b	16.4 ± 0.3	ab	1.4 ± 0.3	a	1.9 ± 0.3	a
Ebro Nase	16	3.6 ± 0.6	b	16.0 ± 0.7	a	1.2 ± 0.2	a	2.3 ± 0.2	a
Brown Trout	17	2.7 ± 0.4	b	16.0 ± 0.3	a	1.0 ± 0.2	a	1.9 ± 0.1	a

adult Kingfishers go immediately to the nest to feed the chicks, so fish-prey does not lose weight by dehydration (Montevecchi & Piatt 1987). Ac-cordingly, the values obtained from fish-prey cap-tured in the river are directly comparable with the prey provided to the chicks. Therefore, all values provided here were expressed on a wet-weight ba-sis.

Once in the laboratory, each individual fish was dried at 105şC until a constant weight was reached (dry mass). The lipids were extracted from this material using petroleum ether in a Soxlet ex-tractor (Reynolds & Kunz 2001) after acid hydro-lysis (CHL). The remaining material was dried and re-weighed (fat-free mass), and then placed in a muffle furnace at 550şC to incinerate the proteins and determine their content using the Kjedahl me-thod (Bradstreet 1954). The resulting ash was then weighed to determine the mineral content. The carbohydrates were the remaining material:% car-bohydrates = 100 – (% lipids +% proteins +% mineral content). The caloric content of each fish-prey was calculated following Jenni and Jenni-Eirmann (1998): lipids (adipose tissues), 39.6 kJ/g; proteins (skeletal muscle and fat-free mass), 17.8 kJ/g, carbohydrates (glycogen), 17.5 kJ/g.

We conducted one-way ANOVAs followed by a Tukey B or Tamhane *a posteriori* test (ac-cording to variance heterogeneity) to check whether there were differences in the relative amount of carbohydrates, proteins, lipids and the relative caloric content between fish-prey species. Complementarily, and due to the possible effect of the zero-sum nature of fish nutritional components (e.g., a fish low in fat would be higher in other components), we conducted a MANOVA on all variables with fish species as a factor.

We used simple linear correlations to assess whether the caloric values of each fish species were correlated with (1) the proportion of each fish-prey in the nest and (2) the Strauss' index, which was calculated as the difference in the rela-tive prey proportion at the nest and in the river but only for the river transects where a given fish-prey was detected [i.e., N'(Table 2)–N' (Table 3)] (Manly *et al.* 2002). Positive values of this index mean positive selection of a prey, whilst negative values indicate prey avoidance.

We also used simple linear correlation tests in order to see whether the caloric content was posi-tively correlated with each nutritional component (i.e. lipid, protein and carbohydrate content).

The SPSS 18.0 for Windows was used for sta-tistics; means are given ± 95% confidence interval.

3. Results

Overall, eight fish-prey species were observed in the nests but two of them [Common Carp (*Cypri-nus carpio*) and Pyrenean Stone Loach (*Barbatula quignardi*)] were very rare (<1% of abundance). The remaining prey species were Ebro Barbel (*Luciobarbus graellsii*), Bermejuela (*Acondro-stoma arcasii*), Pyrenean Gudgeon (*Gobio loza-noi*), Ebro Nase (*Parachondrostoma miegii*), Pyr-enean Minnow (*Phoxinus bigerri*) and Brown Trout (*Salmo trutta*). Common names have been taken as shown by Leunda *et al.* (2009).

The most consumed fish-prey was the Pyre-nean Minnow, and the Ebro Barbel was the less consumed prey (see N' values in Table 2). The Pyrenean Minnow was also the most abundant fish-prey in the rivers and the Bermejuela was the

Table 2. Number of fish-prey identified, number of nests where each fish-prey species was detected (out of ten nests in total), relative abundance concerning all the nests (N) and only those nests where a given fish-prey species was detected (N'), and mean total length (± 95% confidence interval) of fish-prey found at nests.

	N(fish)	N(nest)	N(%)	N'(%)	Length (mm)
Ebro Barbel	102	7	3.3	3.9	60.2 ± 3.4
Bermejuela	123	2	4.0	27.6	53.2 ± 2.3
Pyrenean Minnow	1,704	10	55.0	55.0	55.9 ± 0.5
Pyrenean Gudgeon	295	8	9.5	11.7	66.3 ± 1.5
Ebro Nase	740	10	23.9	23.9	57.8 ± 1.3
Brown Trout	135	9	4.4	4.4	64.7 ± 1.5

Table 3. Number of fish-prey obtained by electrofishing (we have only considered fish-prey species found at nests), number of river transects where a given fish-prey species was detected (out of ten), relative abundance concerning all the rivers (N) and only those rivers where a given fish-prey species was detected (N'), and mean total length (± 95% confidence interval) of fish-prey at rivers. Mean size is calculated for the entire sample of captured fish-prey, including adults.

	N(fish)	N(rivers)	N(%)	N'(%)	Length (mm)
Ebro Barbel	659	10	11.2	11.2	74.5 ± 1.0
Bermejuela	226	1	3.8	23.5	68.8 ± 1.1
Pyrenean Minnow	3,529	10	59.9	59.9	53.8 ± 0.4
Pyrenean Gudgeon	437	8	7.4	9.2	77.2 ± 1.4
Ebro Nase	981	10	16.7	16.7	61.4 ± 1.3
Brown Trout	59	7	1.0	1.2	82.5 ± 3.4

scarcest prey (see Table 3). The Strauss index ranged from -7.2% (Ebro Barbel) to +7.2% (Ebro Nase): Ebro Barbel: -7.2%; Pyrenean Minnow: -4.9%; Gudgeon: +2.5%; Brown Trout: +3.2%; Bermejuela: +4.1%; Ebro Nase: +7.2%.

The proportion of lipids differed between fish-prey species ($F_{5,93} = 18.369$, $p < 0.001$), with the highest values being found in the Bermejuela and the lowest in the Brown Trout and the Gudgeon (Table 1). Similarly, the proportion of proteins also differed ($F_{5,93} = 3.637$, $p = 0.005$), with the highest values being found in the Pyrenean Minnow and without significant differences among the remaining species (Table 1). Although an ANOVA shows significant differences between species ($F_{5,93} = 3.254$, $p = 0.009$), a Tukey-B *a posteriori* test did not detect significant differences in the relative amount of carbohydrates for any of the fish-prey species. The relative caloric content also varied among fish-prey species ($F_{5,93} = 20.242$, $p < 0.001$), with the Bermejuela having the highest values (Table 1). Using a multivariate approach (MANOVA) we detected that, overall, nutritional

components (lipids, proteins, carbohydrates) also differed between species (Pillai's $F_{15,279} = 6.622$, $p < 0.001$). The proportion of lipids was positively correlated with the caloric content of each fish-prey species but not with the proportion of proteins or carbohydrates (lipids: $r = 0.998$, $p < 0.001$; proteins: $r = 0.335$, $p = 0.516$; carbohydrates: $r = 0.701$, $p = 0.121$).

The proportion of each fish-prey species in the nest was not correlated with its proportion of lipids, proteins or carbohydrates, nor with its caloric content, either considering the proportion of each fish-prey at nests or at nests in relation to rivers (Table 4).

4. Discussion

We found that 95% of the fish-prey consumed by the Kingfisher population from northern Iberia comprised of cyprinids and the rest were salmonids. This result agrees with previous studies carried out in the region (Campos *et al.* 2000), as well

Table 4. Pearson linear correlations used to analyse correlations between the caloric content, the proportion of each nutritional component in fish-prey species (n = 6 species) and the proportion of each fish-prey species in the nests and in the nests in relation to rivers.

	Fish-prey consumption (absolute)		Fish-prey consumption (relative)	
	r	p	r	p
% Lipids	–0.147	0.406	+0.044	0.934
% Proteins	–0.208	0.693	–0.242	0.643
% Carbohydrates	+0.330	0.523	+0.005	0.992
Caloric Content	–0.448	0.373	+0.063	0.906

as work from other regions in central Europe (e.g., Čech & Čech 2015). Similarly, mean fish-prey size at the nests was similar to that reported previously within the region (Campos *et al.* 2000) as well as in other areas of Europe (Čech & Čech 2015), which would confirm that the species may prefer to forage on fish ranging between 40 and 80 mm of total length.

From the six fish-prey species detected overall at the study nests, the Bermejuela was observed to have a higher proportion of lipids and the highest caloric content, indicating that the proportion of lipids can be used as a surrogate of caloric content (Schreckenbach *et al.* 2001). By contrast, the Brown Trout was one of the less energetic prey, contradicting a previous study where the species was suggested to be positively selected by the Kingfisher for this reason (Campos *et al.* 2000).

The Bermejuela was not the most consumed prey, either in absolute or relative terms, supporting the hypothesis that the Kingfisher does not fish over the most energetic prey. However, we must note that the Bermejuela was detected only in one out of the six surveyed rivers, and in two out of the ten nests and, overall, it showed a positive Strauss index, which would indicate some degree of preference to forage on this prey. The most consumed prey was the Pyrenean Minnow, a fish with a moderate, intermediate caloric content.

By contrast, this fish showed a higher-than-the-mean proportion of proteins. As compared to the Bermejuela the Pyrenean Minnow was detected in all the (surveyed) rivers of the region and, therefore, it is a better prey to test for the hypothesis of foraging specialization by energy content values. This fish, however, did not seem to be positively selected by Kingfishers, as we observed that its proportion in nests was below the values ob-

tained in rivers. With a similar caloric content as the Pyrenean Minnow the Ebro Nase, a fish also detected in all the survey rivers was, however, proportionally much more consumed by Kingfishers.

Thus, our results suggest that Kingfishers seem to be opportunistic (Novčić & Simonović 2018), or at least they would not seem to select prey in relation to their caloric content, so they probably fish over the most frequent and available fish-prey of an adequate size. To fulfill the demands of their chicks adult Kingfishers should adjust mass load provided to chicks by adapting the foraging rate (i.e., the number of successful hunts per unit time) and the weight of fish-prey (Čech & Čech 2017).

The energy content values obtained in this study were significantly lower than those obtained in other freshwater fishes (e.g., Schreckenbach *et al.* 2001), but this may be due to factors such as body size- or seasonal-associated variations in the caloric content. Thus, previous studies have focused on fish-eating predators bigger than the Kingfisher, which therefore hunt bigger fish-prey. The fish-prey size ranges consumed by Kingfishers mainly correspond to young or immature fish (except for the Pyrenean Minnow), but unfortunately few studies have dealt with this type of fish-prey (but see Elliott 1976). Accordingly, future research should consider in detail how the caloric content of freshwater fish-prey differs with size and season, and how this could have an impact on the Kingfisher's foraging patterns.

Kuningaskalastaja (*Alcedo atthis*) ei valitse energiapitoisimpia saalislajeja

Poikasten ruokintaan liittyvät strategiat voivat vaikuttaa voimakkaasti lisääntymismenestykseen. Kalaa syövillä lajeilla aikuiset voivat maksimoida ravinnonhankinnan tehokkuuden lisäämällä saalisyksilöiden määrää per aikayksikkö tai saalistamalla suuremman energiapitoisuuden omaavaa saalista. Tämän ne voivat saavuttaa suuremmilla saalisyksilöillä tai enemmän kaloreita sisältävillä saalislajeilla. Kuningaskalastaja (*Alcedo atthis*) pesii ja saalistaa yleensä makeanveden ympäristöissä.

Me keräsimme Pohjois-Espanjan jokiympäristöissä pesivien kuningaskalastajien saaliskaloja kymmeneltä pesältä. Määritimme pesiltä havaittujen saalislajien suhteelliset osuudet sekä kuuden yleisimmän saalislajin ravinto- ja kaloripitoisuudet. Saalislajien suhteelliset osuudet eivät korreloineet lipidien, proteiinien, hiilihydraattien eivätkä kalorimäärien kanssa. Kaikkein energiapitoisin laji ei ollut yleisin saalislaji. Tulosten perusteella voidaan päätellä, että kuningaskalastaja ei saalista kaikista energiapitoisimpia lajeja poikasten ruokinta-aikana vaan saalistaa runsaslukuisimpia lajeja opportunistin tavoin.

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