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Diet of a Southwesternmost Population of Montagu's Harrier (*Circus pygargus*) in the Palearctic

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Abstract: Data on Montagu's Harrier biology was gathered in 1992 during a broader survey on birds of prey in the region of Castro Verde (Alentejo, southeastern Portugal), during which pellets and prey remains were harvested in order to study their diet. Main land-use of the study area was extensive cereal crops with fallow fields. A total of 143 pellets collected in perches were analyzed and 1351 items were counted. Invertebrates were the main prey in number (97.2%) and biomass (32.9%). Birds and mammals were also important prey in terms of biomass (30.2 and 28%, respectively), despite its low numbers in relation to all identified prey (4.3 and 1.3%, respectively). Prey weighing less than 30 g was the most frequent (98.1%) with a corresponding biomass of around 62.1%. For prey weighing more than 100 g only Lagomorphs contributed to it, totaling 25% in terms of biomass, despite their remarkably low numbers (0.4% of total prey). This high predation on invertebrates while low on mammals agrees with the known latitudinal trends of diet composition of the Montagu's Harrier - and of some other birds of prey -, along the Palearctic. In this part of Iberia, where large orthopterans are particularly common in extensive cereal fields, strong presence of insects was found in the diet of Montagu's Harrier populations. This feature seems to be related to the abundance of orthopterans in southern Europe.
Key words: *Circus pygargus*; diet; Castro Verde; diet latitudinal trends; invertebrates.

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A Alimentação de uma População de Tartaranhão-Caçador *Circus pygargus* Localizada mais a Sudoeste no Paleárctico

Sumário. Em 1992, em simultâneo com a realização de outros estudos sobre aves de rapina, colheu-se informação relativa à biologia do Tartaranhão-caçador *Circus pygargus* na região de Castro Verde, onde a agricultura extensiva de sequeiro e os pousios são predominantes. Um dos objectivos foi conhecer a sua alimentação, na altura ainda não conhecida no país, tendo-se para isso recolhido regurgitações e restos de presas em poisos desta espécie. Da análise exclusiva das regurgitações (n = 143) foi contabilizado um total de 1351 itens, constituindo os Invertebrados a presa mais importante quer em termos de frequência de ocorrência no total de itens identificados (97,2%) quer em termos de biomassa (32,9%). Contudo, relativamente à biomassa, tanto as aves como os mamíferos são presas ainda assim importantes, com respectivamente 30,2 e 28%, apesar de numericamente serem pouco numerosas, respetivamente 4,4 e 1,3% em frequência. Quanto à classe de tamanho de presa, em Castro Verde, o Tartaranhão-caçador caça preferentemente presas com menos de 30 g (98,1%), a que corresponde uma percentagem de biomassa total de cerca 62,1%. As presas com mais de 100 g, essencialmente Lagomorfos, representam 0,4% em termos de frequência e 25% em biomassa. Este elevado consumo de invertebrados e baixo de mamíferos, no sudoeste da Península Ibérica, ajusta-se ao que é conhecido sobre o padrão de variação latitudinal da sua dieta na Eurásia – tal como acontece com outras aves de rapina. Nesta parte da Península Ibérica, onde a abundância de grandes ortópteros nas searas e pousios é particularmente grande, os estudos apontam com coerência para uma dieta fortemente baseada neste tipo de presa por parte das populações de Tartaranhão-caçador existentes em regiões de predominância de cerealicultura extensiva. Esta característica terá a ver com a maior abundância e acessibilidade de Ortópteros nas regiões do sul da Europa.

Palavras-chave: *Circus pygargus*; dieta; Castro Verde; padrões latitudinais da dieta; invertebrados.

Alimentation d'une Population de Busard Cendré (*Circus pygargus*) Situé Plus au Sud-Ouest de le Paléarctique

Résumé. Au cours d'une étude sur la communauté de rapaces de la région de Castro Verde (Alentejo, Sud-est du Portugal), qui a été lieu pendant les années de 1991 et 1992, beaucoup de donnés ont été recueillies sur la biologie de la population locale du Busard Cendré, la rapace plus caractéristique de la paysage régional – la céréaliculture extensive avec des jachères de long duration. Seulement la caractérisation du régime alimentaire manque de publication. Pendant ces années, des régurgitations (n = 143) et quelques restes de proies ont été recueillis aux perchoirs et 1351 items ont été identifiés et comptés. Les Invertébrés (principalement des orthoptères) étaient la plus importante proie en nombre (97,2%) et aussi en biomasse (32,9%). Les oiseaux et les mammifères étaient également des proies importants en ce qui concerne la biomasse (30,2 et 28%, respectivement), malgré son faible nombre par rapport à la totalité des proies identifiées (respectivement 4,3 et 1,3%). La présence des proies avec poids inférieure à 30 g était

également la plus fréquente (98,1%), et avec un pourcentage de biomasse correspondant à environ 62,1%. Pour les proies de plus de 100 g, seuls les Lagomorphes étaient importants en ce qui concerne la biomasse (25%), malgré leur faible nombre consommé (0,4% du totale). Cette prédation élevée sur des Invertébrés et très bas sur les mammifères est d'accorde avec les tendances latitudinaux connus dans la composition du régime de ce busard et d'autres prédateurs ailés européennes. Dans cette partie de la péninsule ibérique, où les gros orthoptères sont particulièrement répandus dans les vastes champs de céréales, plusieurs études font état d'une présence constante d'insectes dans l'alimentation des populations du Busard cendré habitant dans les zones où dominent les cultures de céréales et de jachères. Cette caractéristique semble être liée au fait que les orthoptères sont plus abondants et accessibles dans le sud de l'Europe.
Mots-clés: *Circus pygargus*; sud-ouest de la péninsule ibérique; tendances latitudinaires; Invertébrés.

Introduction

Feeding ecology of a bird of prey, like other birds, is a key for understanding their ecology and also for defining conservation measures, since food is a primordial and determining factor (*e.g*. NEWTON, 1979; KORPIMÄKI, 1986; VILLAGE, 1990; KORPIMÄKI and NORRDAHL, 1991; VIÑUELA and VEIGA, 1992; BUTET and LEROUX, 1993; ARROYO, 1998). Data on diet is thus a central chapter to be assessed, since it allow further research on the quality and availability of both food resources and foraging habitats and to study its effects on the population demography of the species and its conservation status.

Until 1992, the information on the biology of the Montagu's Harrier (*Circus pygargus*) in Portugal was anecdotal, and therefore, in the context of other more general studies on birds of prey of Castro Verde region (ONOFRE, 1996), data was collected on the diet of this species (ONOFRE, 1994). While aspects of its biology and ecology have already been published (*e.g*., ONOFRE, 1994, 1995a, 1995b), data on its diet remain to be published. Only a brief summary of the results have been presented elsewhere (*e.g*. ONOFRE, 2001). Meantime, some studies on the diet of Montagu's Harrier have been carried out in the country - *e.g*. in Serra da Malcata by SILVA *et al*. (1995), in the same region of Castro Verde by FRANCO *et al*. (1998) and REIS *et al*. (2001), and near Évora, also in the south, by RIBEIRO *et al*. (2006). Nowadays, in terms of food ecology, this species is one of the best studied birds of prey in Portugal and the same holds true for the Palearctic. Many studies on the food ecology of Montagu's Harrier are available, beginning with THIOLLAY (1968) in western France, and more recently by MIRSKI *et al*. (2016) in eastern Poland. ARROYO *et al*. (2004) and TERRAUBE and ARROYO (2011) provided an excellent picture about the diet of this species on the western Palearctic and its variation along with latitude, longitude and habitat.

Considering the wide range of its diet and prey choice, the Montagu's Harrier is typically a generalist along its range, from western Europe to Russia (ARROYO, 1997; TERRAUBE and ARROYO, 2011), although in many places it seems to rely in some way on rodents (mainly *Microtus arvalis*) (THIOLLAY, 1968; MAUREL and MAUREL, 1984; BUTET and LEROUX, 1988, 1993; SALAMOLARD *et al*., 2000; MILLON *et al*., 2002; TRIERWEILER *et al*., 2006; HÖLKER and WAGNER, 2006; KOKS *et al*., 2007). Elsewhere, in regions such as the southwest of the Iberian Peninsula, orthopteran are taken in large amounts (HIRALDO *et al*., 1975; CORBACHO *et al*., 1993, FRANCO *et al*., 1998; RIBEIRO *et al*., 2006). High numerical frequencies of 92% of bush crickets (Tettigoniidae)

(FRANCO *et al*., 1998) or 87% of Common voles (*M. arvalis*) (SALAMOLARD *et al*., 2000) in the diet does not make this Harrier a specialist, but rather an opportunistic predator taking advantage of the high availability of a particular prey (KORPIMÄKI and MARTI, 1995; REDPATH and THIRGOOD, 1999; TERRAUBE and ARROYO, 2011).

Study area and methods

Study area

The study area was in Castro Verde county (37º38'-37º44'N and 7º50'-8º01'W), in a region characterized by the predominance of extensive cereal cultivation. In 1992, the land use consisted of 56% of fallow, 10% of plowed land, 14%, 13% and 5% of oat, wheat and barley crops, respectively, and 2% of bush patches of gum rockrose (*Cistus ladanifer*) (ONOFRE, 1995a). Holm oak (*Quercus rotundifolia*) and olive groves comprise 7 and 4% of the total area, respectively (ONOFRE, 1995a). All harrier semi-colonies were established in wheat and barley fields with a minimal distance of 10 meters between nests (ONOFRE, 1994, 1995a).

Methods

The food material used in this study were pellets (n = 143), collected from adults and some juvenile perches. Most of these pellets (n = 129) were obtained around the two largest semi-colonies detected (ONOFRE, 1994, 1995a). Prey remains were not considered due to their relatively small number. The remaining 14 pellets were collected around two other smaller semi-colonies of the study area, with 2 and 4 nests. Pellets were stored frozen and later dissected in water, as needed.

Pellets were gathered at irregular intervals from June to early August, through 2 to 6 collections. More than 90% of the pellets were obtained between the end of June and the first week of July.

The identification of Arthropods and in particular Ortopterans was based on PASCUAL (1978), CHINERY (1986), AGUIRRE *et al*. (1987), LEPLEY (1994) and BELLMANN and LUQUET (1995), and in the Insect collection of the National Institute for Agrarian Research (Oeiras, Portugal), as well as in a personal

invertebrate collection. Mammals were identified to the genus level using TEERING (1991). Regarding birds, feathers were identified to the genus or species level by using the Bird Skin collection from the Bocage Museum of the Faculty of Sciences of the University of Lisbon. The invertebrates were counted according to the maximum number of homologous parts, right or left, which in the case of orthopterans were mostly mandibles. Only in the absence of these were other pieces counted: *genitalia*, *pronota*, femurs, etc. Regarding vertebrates, identifiable bone remains were rarely found in pellets, so only one individual of each species was considered after identification of hairs, scales and feathers present in the pellets.

In order to convert prey frequencies in to biomass, weights in ROCHA (1995) were adopted for invertebrates, while for birds the average weights of specimens from closest populations in CRAMP (1998) were used, and for mammals the ones described by CASTELLS and MAYO (1993) were used, with some adaptations for both Portuguese small mammals and juveniles of Leporidae according to A. Mira (pers. comm.). These last were arbitrarily assumed to be juveniles following the observations of HIRALDO *et al*. (1975) and ARROYO (1995). For birds identified as juveniles, 90% of the adult weight was assumed following BIELEFELDT *et al*. (1993). For missing cases weights adopted by HIRALDO *et al*. (1975) and ARROYO (1995) were used.

In addition to the analysis of the taxonomic classes of prey, the diet was also analyzed according to weight classes following CORBACHO *et al*. (1995).

Contingency tables (χ^2 adjustment) were used to compare the samples collected from the three separate sites. To compare similarities between the results of this study to those of other authors only multivariate exploratory and graphic techniques, such Cluster Analysis (CA) and Principal Component Analysis (PCA), were used, since TERRAUBE and ARROYO (2011) used linear models. Several distances measures (Euclidean, Manhattan and Chebychev), and linkage methods (Complete linkage, UPGMA, WPGMA and Ward's method) were examined in CA.

In order to test if the distribution of prey items in the 143 pellets had random or regular distributions (H_o: $|d| \leq 1.96$), in particular concerning invertebrates, the index of dispersion $ID = s^2/\bar{X}$ -, which statistics is $d = \sqrt{2\chi^2} - \sqrt{2(N-1)-1}$, with $\chi 2 = \left[\sum_{i=1}^{n}(xi - \bar{x})\frac{2}{x}\right] = ID(N-1)$ (LUDWIG and REYNOLDS, 1988) was used.

Out of the many studies with information on the harrier diet, in which food data came from different methods (anecdotal and disperse notes, stomach contents, pellets, remains, direct and video observations), thirty populations

studied in different space and time were taken into account in the PCA and CA analyses (THIOLLAY, 1968; HIRALDO *et al*., 1975; SCHIPPER, 1977; UNDERHILL-DAY, 1993; CASTAÑO, 1995; SILVA *et al*., 1995; GIACCHINI *et al*., 1995; ARROYO, 1997; FRANCO *et al*., 1998; MARTINEZ *et al*., 1999; SALAMOLARD *et al*., 2000; GÖTZ, 2002; MILLON *et al*., 2002; CORBACHO *et al*., 2005; TABOR and TABOR, 2005; HÖLKER and WAGNER, 2006; RIBEIRO *et al*., 2006; TRIERWEILER *et al*., 2006; WIACEK and NIEDZWIEDZ, 2005, 2009; KOKS *et al*., 2007; HOLKER, 2008; MIRSKI *et al*., 2016; present work). For the purpose of comparison, only studies done using pellets alone or in combination with remains, if the lasts did not surpass 10% of the total prey items, were considered. Seven main taxonomic classes of prey were taken into account in these analyses: Invertebrates, amphibians, reptiles, birds, eggs, mammals, others. Data on prey classes were arcsine transformed, and Pearson correlation coefficient was used whenever needed. STATISTICA 6.1 (StatSoft, Inc., 1984-2003) was used as statistical software.

Results

There were no significant differences in diet composition among the three sites in the study area ($\chi^2_{10} = 11.937$; $p > 0.05$), when seven large classes of prey were considered: Orthoptera, other invertebrates, reptiles, birds, eggs and mammals [K = 7]). Therefore, the samples of the four semi-colonies were assembled. Concise results are presented in Table 1, but a detailed description is shown in Appendix 1.

Table 1 - Diet composition of Montagu's Harrier in Castro Verde/Southeastern Portugal based in pellets (n = 143). Summary (*cf*. Appendix 1)

	Absolute frequence	Relative frequence (%)	Biomass (g)	Percentage of Biomass	Frequency of Occurrence in Pellets
INVERTEBRATES	1233	91.3	1974.1	32.9	97.2
ORTHOPTERA	1179	87.3	1941.1	32.4	95.8
OTHER INVERTEBRATES	54	4.0	33.0	0.6	15.6
VERTEBRATES	118	8.7	4023.5	67.1	51.1
REPTILES	28	2.1	280.0	4.7	19.6
BIRDS	59	4.4	1812.5	30.2	33.6
EGGS	14	1.0	252.0	4.2	9.8
MAMMALS	17	1.3	1679.0	28,0	11.2
Total Items	1351		5997.7		

A total of 1351 preys were counted, with an average of 9.4 items per pellet, and a maximum and a minimum of 35 and 1 preys by pellet, respectively. In terms of taxonomic classes, orthopterans are the most frequent prey both in Frequency of Occurrence in pellets (FO) (95.8%), and in Relative Frequency (FR) (87.3%).

Among these, bush-crickets (Tettigoniidae) are undoubtedly the predominant insects, with FO = 93.0% and FR = 75.1%, being *Decticus albifrons* (FR = 41.4%) and *Tettigonia viridissima* (FR = 21.8%) the most important prey species (see Appendix 1). The ID test on the distribution of prey in the pellets showed that the distribution of the majority of invertebrates and of all Orthoptera is aggregated ($d > 1.96$, $p < 0.05$), meaning that the Harrier usually consumes such prey in a consecutive way. This agrees with the observed hunting pattern of Montagu's Harrier's females, which were seen mostly foraging over the crops and fallows near the nests, seizing small prey, apparently orthopterans (ONOFRE, 1995b).

Among vertebrates, the most captured prey were birds (FO = 33.6%; FR = 4.4%), mostly small Passeriformes (FR = 4.2%), with predation on eggs matching FO = 9.8% and FR = 1.0%. Scales of reptiles were found rather frequently in pellets (FO = 19.6%), but the numerical frequency was low (FR = 2.1%), and were probably mainly *Psammodromus algirus*. Mammals were the least frequent prey (FO = 11.2%, FR = 1.3%), being mostly small mammals (FR = 0.8%). The distribution of vertebrate *taxa* in the pellets was random both by taxonomic Class ($|d| < 1.96$; $p > 0.05$) and globally ($|d| = 1.770$, $p > 0.05$, n = 118 items).

A balance was seen in the main taxonomic classes of prey in terms of Percentage of Biomass (PB) of the Montagu's Harrier diet: Invertebrates PB = 32.9%; birds + eggs PB = 34.4% (birds PB alone = 30.2%); mammals PB = 28%; reptiles being the only exception, PB = 4.7%. However, these figures are merely indicative, given the successive errors in the estimation of the relative frequencies and in the conversion into biomass of the different *taxa* (see MARTI, 1978; BIELEFELDT *et al*., 1993). It should also be noted that the specific biomass of orthopterans may be somewhat conservative (ranging 1.5 - 2 g), and so the total biomass of invertebrates may be underestimated.

In terms of prey weight classes (Figure 2), Montagu's Harrier captures mainly prey weighing less than 30 g, - FO = 99.3%, FR = 98.1% -, which include invertebrates, small birds (Passeriformes) and small mammals, totalizing 62.1% of the biomass. Prey weighing more than 100 g were exclusively Leporidae (most likely *Lepus granatensis*), which are of importance despite their very small

numerical representation (FR = 0.4%), matching about 25% of the total consumed biomass.

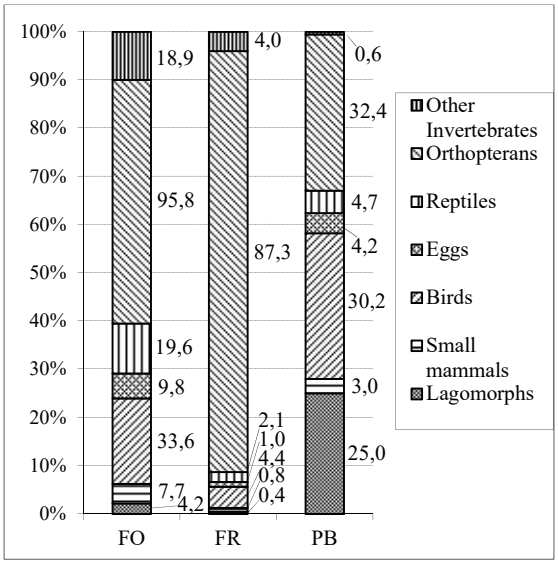


Figure 1 - Frequency of Occurrence in pellets (FO), Relative or Numeric Frequency (FR) and Biomass (PB) of main prey taxonomic classes in the Montagu's Harrier diet in Castro Verde

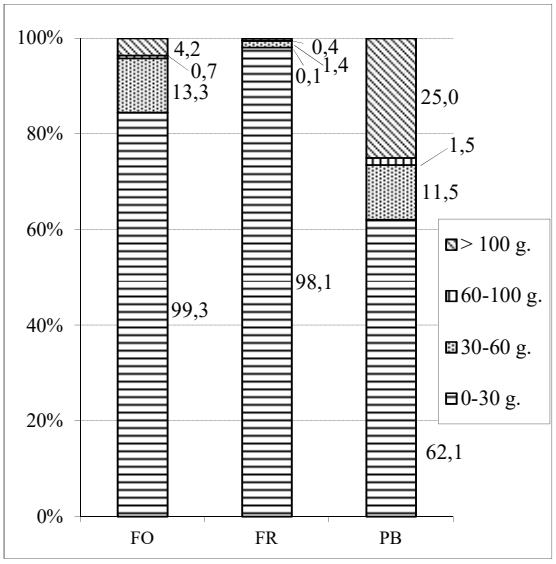


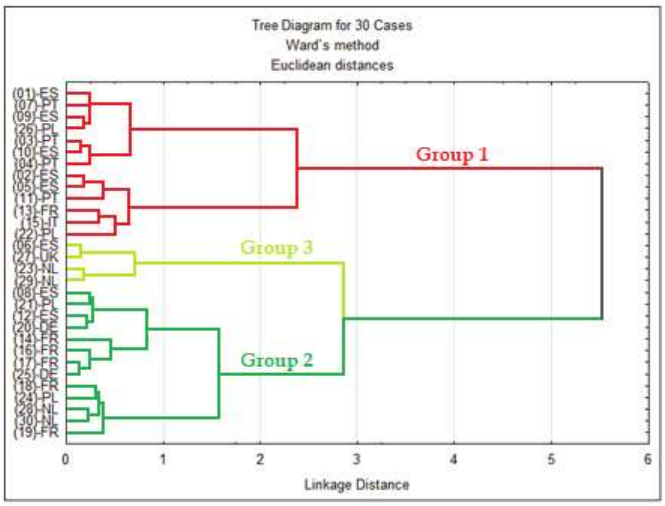
Figure 2 - Frequency of Occurrence (FO), Relative Frequency (FR) and Biomass (PB) of prey weight classes in the Montagu's Harrier diet in Castro Verde

The different distance measurements and linkage methods used in the CA, based on the numerical frequencies of six main taxonomic types of prey (Invertebrates, amphibians, reptiles, birds + eggs, mammals, others), gave similar results. Figure 3 illustrates the results obtained with the Euclidean distance metric and the Ward's linkage method of the 30 diet studies quoted at the section of Methods. The diet found in the present work is typical of the Montagu's Harrier populations in the southwestern Iberian Peninsula, with strongest similarities with the nearby populations which breed also in cereal and fallow landscapes, and which were studied by FRANCO *et al*. (1998) and CORBACHO *et al*. (2005). Such diets are largely insectivorous, with orthopteran predominating by far. PCA shows similar results (Table 2, Figure 4).

In all dendrograms generated by the different metric distances and linkage methods (Figure 3), as well as in the PCA factor-plane (Figure 4), there is a great affinity among the diets in Castro Verde, southeastern Portugal (FRANCO *et al*., 1998, ONOFRE, present work), and those found in Extremadura, Southwestern Spain, namely from the populations nesting in arable land in Orellana, Cornalvo and Llanos de Badajoz, or in the grasslands of La Serena (CORBACHO *et al*., 2005), as well as in the salt marshes of Isla Cristina, Huelva (HIRALDO *et al*., 1975). To these diets we should add some others, such as the one in Évora, in southern Portugal (RIBEIRO *et al*., 2006), and the diet found by MIRSKI *et al*. (2016) in Biala Podlaska, Eastern Poland, in arable land and rich in invertebrates, as well as others richer in birds found in Sierra Pelada (Huelva) (HIRALDO *et al*., 1975), Camargue/La Crau (SCHIPPER, 1977), and Urbino (Pesaro) GIACCHINI *et al*., 1995) (Group 1; *cf*. Figure 3). With a rather different trophic spectrum from the group referred to above, there are diets in the Netherlands, Germany, England and northern France where few invertebrates are caught but birds and, mainly, mammals are the common prey (*e.g*. THIOLLAY, 1968; SALAMOLARD *et al*., 2000; GÖTZ, 2002; MILLON *et al*., 2002; WIACEK and NIEDZWIEDZ, 2005, 2009; HÖLKER and WAGNER, 2006; KOKS *et al*., 2007, HOLKER, 2008) (Groups 2 and 3; *cf*. Figure 3).

We found an inverse correlation among the proportion of invertebrates and reptiles *versus* latitude (respectively, r = -0.595, $p < 0.001$; r = -0.533, $p < 0.01$), and a positive one between mammals and latitude (r = 0.622, $p < 0.001$) (Table 2), in agreement with TERRAUBE and ARROYO (2011). However, no correlation was found among diet diversity and latitude, due to very low Shannon diversity scores found in southernmost diets (FRANCO *et al*., 1998; CORBACHO *et al*., 2005; ONOFRE, present work), and in some northernmost ones (*e.g*. UNDERHILL-DAY, 1993; MIRSKI *et al*., 2016).

a)



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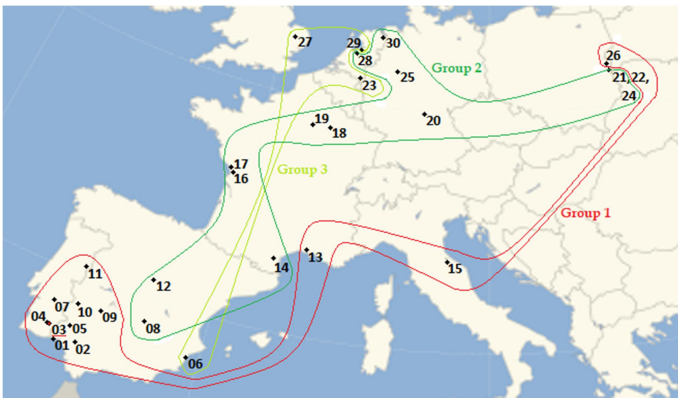

Figure 3 - Similarities between the diet of Montagu's Harrier in Castro Verde and the diets of other populations in Europe. An example using Cluster Analysis and the Ward's linkage method with Euclidean distance metrics

Legend: (03)-PT = ONOFRE (present work); (01)-ES = HIRALDO *et al.* (1975); (02)-ES = HIRALDO *et al.* (1975); (04)-PT = FRANCO *et al.* (1998); (05)-ES = HIRALDO *et al.* (1975); (06)-ES = MARTINEZ *et al.* (1999); (07)-PT = RIBEIRO *et al.* (2006); (08)-ES = CASTAÑO (1995); (09)-ES = CORBACHO *et al.* (2005); (10)-ES = CORBACHO *et al.* (2005); (11)-PT = SILVA *et al.* (1995); (12)-ES = ARROYO (1997); (13)-FR SCHIPPER (1977); (14)-FR = MAUREL and MAUREL (1984); (15)-IT = GIACCHINI *et al.* (1995); (16)-FR = SALAMOLARD *et al.*. (2000); (17)-FR = THIOLLAY (1968); (18)-FR = MILLON *et al.* (2002); (19)-FR = MILLON *et al.* (2002); (20)-DE = GÖTZ (2002); (21)-PL = TABOR and TABOR (2005); (22)-PL = KROGULEC *cit. in* ARROYO *et al.* (2004); (23)-NL = SCHIPPER (1977); (24)-PL = WIACEK AND NIEDZWIEDZ (2005, 2009); (25)-DE = HÖLKER AND WAGNER (2006), HOLKER (2008); (26)-PL = MIRSKI *et al.* (2016); (27)-UK = UNDERHILL-DAY (1993); (28)-NL = TRIERWEILER *et al.* (2006); (29)-NL = SCHIPPER (1977); (30)-NL = KOKS *et al.* (2007) (See text for further details).

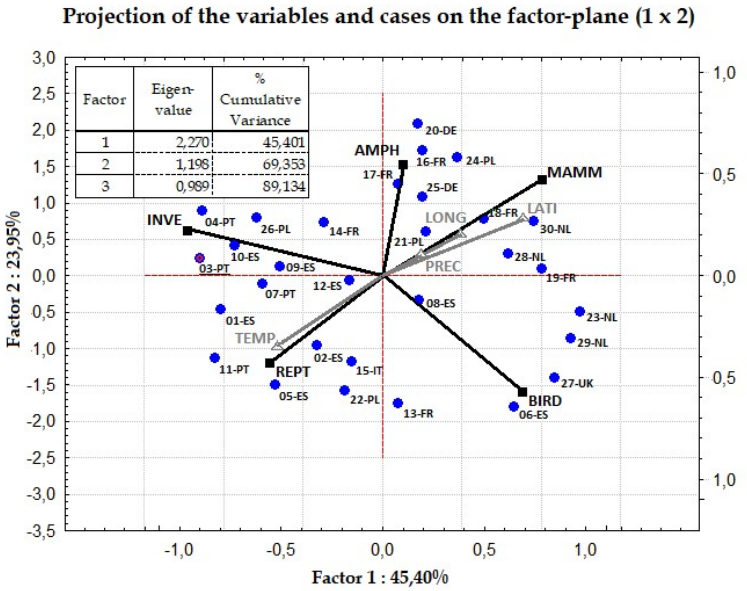

Figure 4 - Resemblance and weight of prey classes of the diet Montagu's Harrier in Castro Verde and remainder European populations. The PCA standpoint

Legend: (03)-PT = ONOFRE (present work); • = Other european harrier diets (see legend of Figure 3); ■ Prey classes factor correlation: INVE = invertebrates; MAMM = mammals; BIRD = birds; REPT = reptiles; AMPH = amphibians; Δ = supplementary variables (StatSoft, Inc. 1984-2003). LONG = Longitude; LAT = Latitude; PREC = Precipitation; TEMP = Temperature.

Table 2 - Latitude and longitude correlation with the Shannon diversity index and some prey classes for 30 diet studies of Montagu's Harrier

	Latitude		Longitude	
	r	p	r	p
Prey Class				
Invertebrates	-0,595	0,001	-0,317	0,088
Amphibians	0,275	0,141	0,383	0,037
Reptiles	-0,533	0,002	-0,198	0,293
Birds	0,289	0,122	0,221	0,241
Eggs	0,391	0,033	0,207	0,272
Mammals	0,622	0,000	0,323	0,082
Diversity H'(ln)	0,290	0,120	0,349	0,059

Legend: r = Pearson correlation coefficient.

Discussion

The results show a strong resemblance between the diet found in this study and the one found by FRANCO *et al*. (1998), which is due to the strong proximity in space and time of both studies. Both took place in Castro Verde county, southern Portugal, and the food items were collected with an interval of 2 years of difference. Invertebrates and orthopterans, in particular, are the most frequent prey found in the pellets of Montagu's Harrier in Castro Verde. This seems to be a feature of Iberian populations also (*cf*. HIRALDO *et al*., 1975; SILVA *et al*., 1995; ARROYO, 1997; FRANCO *et al*., 1998; CORBACHO *et al*., 2005; RIBEIRO *et al*., 2006; ONOFRE, pres. work). In terms of numerical frequency, orthopterans make up more than half of the diet items of the Harrier populations in this geographic region, up to 91% in the present work, and a maximum of the 97% as reported by FRANCO *et al*. (1998). The proportion of invertebrates captured in the Portuguese Alentejo and in the Spanish Extremadura regions are the highest known (more than 75%). This is much higher than those found in other areas of Spain and France, even in the same kind of habitat – cereal crops and fallow or pasture land. This seems to be related with the availability of the more numerous preys, since Montagu's Harrier is an opportunistic predator (ARROYO, 1997; TERRAUBE and ARROYO, 2011). Habitat could also influence prey capture and diet composition (TERRAUBE and ARROYO, 2011), but diets of Montagu's Harrier breeding in habitats other than cereal crops and fallow fields in the Iberian Peninsula are also rich in invertebrates (*cf*. HIRALDO *et al*., 1995; SILVA *et al*., 1995). In the Iberian Peninsula the consumption of invertebrates, or orthopterans, is high even in mountains and shrublands – up to 51% in Sierra Pelada (HIRALDO *et al*., 1995), and 60% in Serra da Malcata (SILVA *et al*., 1995) -, or in some salt-marshes – 77% in Isla Cristina (HIRALDO *et al*., 1995). The climate of almost all these study areas is characterized as Hot Dry-Summer Mediterranean (Csa) (KOTTEK *et al*., 2006; BECK *et al*., 2018), which are ideal conditions for the presence of highest richness of orthopteran species in Europe (COLINS and WELL, 1987; HOCHKIRCH *et al*., 2006). The Iberian Peninsula, in particularly, is known to have a remarkably rich and abundant orthopteran fauna (COLINS and WELL, 1987; LLUCIÀ-POMARES, 2002).

The high proportion of invertebrates in the diet of the present work (91,3%) fits well with the latitudinal trend of invertebrates found along the diets of Montagu's harrier European populations, which numerical proportion steadily increase to the south ($r = -0{,}5673$, $p < 0{,}001$, all diets except the present work). The proportions of reptiles (2,1%), mammals (1,3%) and birds (4,4%) in the diet

of the present work also fits very well the observed European latitudinal trends of these prey classes (Reptiles: r = -0.5391, p = 0.003; Mammals: r = 0.5992, p = 0.001; Birds: r = 0.2487, p = 0,193; all diets except the present work; see also TERRAUBE and ARROYO (2011)).

Increasing consumption of invertebrates (insects) and reptiles and decreasing consumption of small mammals as we move south was also noticed in other small-medium species of birds of prey such as the Eurasian Kestrel (*Falco tinnunculus*) (VILLAGE, 1990; FATTORINI *et al.,* 1999), the Eurasian Buzzard (*Buteo buteo*) (BUSTAMANTE,1985), or the Western Barn-owl (*Tyto alba*) (HERRERA, 1974). The variation in the proportions of small mammals and of invertebrates captured along the latitudinal gradient seems to reflect a strong local opportunistic character of these species. This was also reported by ARROYO (1997) for the Montagu's Harrier, where the variation in diet patterns can be largely explained by prey patterns and latitudinal distribution of prey (PIANKA, 1966; DELIBES, 1975; KORPIMÄKI and MARTI, 1995). In central and northern Europe, voles, such as the *M. arvalis*, are very common and abundant and all these species of birds of prey opportunistically prey on them, while in the Mediterranean region small mammal richness and density are lower (HERRERA, 1974; DELIBES, 1975), and so grasshoppers are the abundant alternative prey in turn.

Conclusions

The most frequently prey caught in Castro Verde is rather small in size, with a weight smaller than 30g, being Insects the main prey. Based on observed behavior (ONOFRE, 1995b) adult females seem to be responsible for the largest contribution of insects in the diet, which as rule are large: *Tettigonia veridissima* and *Decticus albifrons,* among the Tettigonids, and *Locusta migratoria* and *Anacridium aegypitum*, among the Acridids, species which are widespread and very common all over the Iberian Peninsula (PINA *et al*., 2017). Orthopterans are a very important part of the diet in Castro Verde/Alentejo as well as in great part of southwestern Iberia (Portuguese Alentejo and Spanish Extremadura and Andalusia), where the bulk of Iberian Montagu's Harrier population is located, nesting mainly in cereal crops (CALDERÓN *et al*., 1995; ONOFRE and RUFINO, 1995; GARCÍA and ARROYO, 2003; ALMEIDA *et al*., 2005). The orthopterans in the diets of these harrier populations total 78 - 98% in number and 17 to 67%

relative to biomass (CORBACHO *et al*., 1995, 2005; FRANCO *et al*., 1998, REIS *et al*., 2001, present work).

Large numbers of Montagu's Harrier in the Iberian Peninsula depend on cereal crops and fallows either for feeding or for nesting, although nest destruction and reproductive failure occur significantly due to harvesting of cereal crops (ARROYO and GARCÍA, 2004; ALMEIDA *et al*., 2005). Extensive cereal farmland is steadily in serious decline in Portugal (ONOFRE and RUFINO, 1995; INE, 2019) and are threatened to be converted in to intensive and irrigated agriculture (olive groves, almond orchards, corn crops and vineyards), which in the long term, besides habitat loss, will cause breeding success decline due to diminishing of food resources – the orthopterans. Because of this threat, common agricultural policy (CAP) agri-environmental measures should be continued or even monetarily reinforced in areas important for the Montagu's Harrier, such as many of Natura 2000 network Special Protection Areas (SPAs) in the Alentejo, to maintain extensive cereal crops and fallow land.

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APPENDIX 1

Full spectrum of the diet composition of Montagu's Harrier in Castro Verde/Southeastern Portugal (No. of pellets = 143)

	Absolute frequence	Relative frequence (%)	Biomass (g)	Percentage of Biomass	Frequency of Occurrence [1]
INVERTEBRATES	1233	91.3	1974.1	32.9	97.2
INSECTS	1215	89.9	1964.6	32.8	97.2
Orthoptera	1179	87.3	1941.1	32.4	95.8
Tettigonidae	1014	75.1	1723.8	28.7	93
Tettigonia viridissima	295	21.8	501.5	8.4	46.9
Decticus albifrons	559	41.4	950.3	15.8	74.8
Tessellana tessellata	105	7.8	178.5	3	20.3
Platycleis sp.[2]	39	2.9	66.3	1.1	21.7
Tettigonidae n.id.	16	1.2	27.2	0.5	9.1
Gryllidae	1	0.1	1.7	0	0.7
Gryllidae n.id.	1	0.1	1.7	0	0.7
Gryllotalpidae	2	0.1	8	0.1	1.4
Gryllotalpa gryllotalpa	2	0.1	8	0.1	1.4
Acrididae	161	11.9	206.1	3.4	35.7
Anacridium aegyptium	44	3.3	56.3	0.9	9.8
Locusta migratotia solitaria	29	2.1	37.1	0.6	9.8
Acrididae n.id.[3]	88	6.5	112.6	1.9	26.6
Orthoptera n.id.	1	0.1	1.5	0	0.7
Other insects	36	2.7	23.6	0.4	15.4
Hemiptera	3	0.2	0.8	0	1.4
Neuroptera	6	0.4	6	0.1	3.5
Lepidoptera	5	0.4	5	0.1	1.4
Coleoptera	17	1.3	6.8	0.1	9.8
Insects n.id.	5	0.4	5	0.1	2.8
Other invertebrates	18	1.3	9.5	0.2	6.3
Chilopoda	2	0.1	4	0.1	0.7
Arachnida	15	1.1	4.5	0.1	5.6
Arthropoda n.id.	1	0.1	1	0	0
VERTEBRATES	118	8.7	4023.5	67.1	51.1
REPTILES	28	2.1	280	4.7	19.6
Psammodromus sp.[4]	27	2	270	4.5	18.9
Sauria/Serpentes n.id.	1	0.1	10	0.2	0.7
BIRDS	59	4.4	1812.5	30.2	33.6
Coturnix coturnix	1	0.1	87.3	1.5	0.7
Galerida sp.	7	0.5	234	3.9	4.9
Alaudidae n.id.	1	0.1	40	0.7	0.7
Hirundo daurica	1	0.1	20	0.3	0.7
Saxicola torquatus	2	0.1	30	0.5	1.4
Oenanthe hispanica	1	0.1	18	0.3	0.7
Lanius senator	7	0.5	226.8	3.8	4.9
Passer sp.	6	0.4	162.4	2.7	4.2
Serinus serinus	1	0.1	10.8	0.2	0.7
Carduelis carduelis	1	0.1	14	0.2	0.7
Linaria cannabina	1	0.1	19	0.3	0.7
Emberiza calandra	3	0.2	135	2.3	0.7
Passeriformes n.id.	26	1.9	763.2	12.7	17.5
Aves n.id.	1	0.1	52	0.9	0.7
EGGS	14	1	252	4.2	9.8
MAMMALS	17	1.3	1679	28	11.2
Leporidae[5]	6	0.4	1500	25	4.2
Microtus sp.[6]	4	0.3	72	1.2	2.8
Apodemus sylvaticus	1	0.1	21	0.4	0.7
Mus sp.[7]	4	0.3	52	0.9	2.8
Soricidae/Muridae n.id.	2	0.1	34	0.6	1.4
TOTAL	1351		5997.7		

Legend: [1] Percentage of occurrence of items in pellets; [2] 90% are *P. falx*; [3] 5 are *Pamphagidae*; [4] Probably mostly *P. algirus*; [5] Probably mostly *Lepus granatensis*; [6] Probably *M. duodecimcostatus*; [7] Probably mostly *M. spretus*; n.id. = non identified.