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Feeding habits of the Short-toed Eagle *Circaetus gallicus* during the breeding period in Central Italy

Federico Cauli[1,2], Matteo Riccardo Di Nicola[3,4]*, Paolo Audisio[1], Francesco Petretti[5] & Francesco Paolo Faraone[6]

[1]Department of Biology and Biotechnology, Sapienza University of Rome, Rome, Italy
[2]Stazione Romana Osservazione e Protezione Uccelli (S.R.O.P.U.), Rome, Italy
[3]IRCCS San Raffaele Hospital, Unit of Dermatology, Via Olgettina 60, 20132 Milan, Italy
[4]Asociación Herpetológica Española, Apartado de Correos 191, 28911 Leganés, Madrid, Spain
[5]Department of Chemistry Biology and Biotechnology, University of Perugia, Perugia, Italy
[6]Viale Regione Siciliana S.E., 532, 90129 Palermo, Italy

*corresponding author: dinicola.matteo@hsr.it

MRDN: 0000-0001-7199-0804

Abstract - Short-toed Eagle *Circaetus gallicus* is the only snake eagle that nests in the Palearctic. Its diet has been studied in several European countries and it is essentially based on reptiles. The aims of this work were to characterise the feeding habits of Short-toed Eagle breeding in the Tolfa Mountains (Central Italy) including a comparison of the diet with that of other populations. Moreover, we assessed changes in the diet of the former population using published data collected more than 35 years ago. We monitored five nests and three roosts between 2020 and 2021. Using camera traps and the collection and analysis of feeding remains, a total of 247 prey items were identified. The diet of the sampled nests/individuals was clearly snake-based (93.5% of prey spectrum). We found no significant differences between the diet of nestlings and adult individuals. The main prey was the Western Whip Snake *Hierophis viridiflavus* (83% of snakes captured), probably due to its high availability in the environment and its average size, which is positively selected by the Short-toed Eagle. Long-term comparison with previous data shows an over time contraction of the diet breadth with a relative increase of Western Whip Snake compared to other prey. The same pattern is observed in long-term studies on the snake community of our study area and is probably linked to both local anthropogenic impacts and global warming, which tend to favour thermophilic and generalist snake species During the reproductive period our population showed a narrower diet breadth when compared to the diet of other Mediterranean sites, but a similar overall structure, with a comparable frequency of snakes. The populations with the wider diet breadth are those located in areas with a greater abundance of thermophilic snake species of medium to large size, such as France, Spain and Greece.

Keywords: Snake Eagle, diet, bird of prey, ophidians, reptiles consumption, Latium

INTRODUCTION

Among snake eagles, the Short-toed Eagle *Circaetus gallicus*, is the only species that nests in the Palaearctic (Cramp & Simmons 1980). Contrary to what is observed in many diurnal raptors, males of this species are only slightly smaller and lighter than females; such a low size dimorphism could depend on the type of prey hunted (Newton 1979).

The reproductive habitat of the Short-toed Eagle mainly includes environments with a temperate climate, characterised by wooded areas suitable for nesting (Bakaloudis et al. 2000, 2001), and pastures or cultivated areas exploited as hunting grounds (Bakaloudis 2009).

The Short-toed Eagle is distributed from North-West Africa and South-West Europe North to Gulf of Finland and East to Lake Balkhash, North-West China and North-West/North Mongolia and, in South, to Asia Minor, Levant countries, S Caucasus and West/North Iran; Indian Subcontinent; Lesser Sundas. Western populations winter in Sahel zone of Africa; Eastern populations winter in South/South-East Asia, some South to Greater Sundas (Orta 2020). Most of the European population is found in the Mediterranean area, except for the islands, probably because the species avoids crossing long stretches of sea (e.g. Agostini et al. 2015). In the Palaearctic, Short-toed Eagle is a migratory species that does not move in large groups. Migrating individuals mainly overwinter in North Africa (Ferguson-Lees & Christie 2001). The European Breeding Birds Atlas (Keller et al. 2020) records an apparent reduction in the reproductive area in Europe and the Baltic countries. However, the overall European population should be stable. Since the 1980s, the Italian population of Short-toed Eagle has increased and it has undergone a territorial expansion (Brichetti & Fracasso 2020). The breeding population in Latium (central Italy) has grown from 20-30 pairs in the early 1980s to 54-82 in the early 2000s (Aradis et al. 2012). There was also an increase in the Tolfa mountains: from 11 breeding pairs estimated at the end of the 1980s (Petretti 1988) to 20-24 pairs in 2007 (Ceccarelli & Ricci 2007), and finally to 29 pairs in 2020 (Cauli et al. 2021).

Short-toed Eagles always nest on trees, even of modest height. The species lays only one egg, which is incubated for 45-47 days. The first flight occurs when the young bird is 60-80 days old (Ferguson-Lees & Christie 2001). The Short-toed Eagle diet is essentially based on reptiles as shown by various studies carried out in several countries, such as Spain (Amores & Franco 1981, Gil & Pleguezuelos 2001, Moreno-Rueda & Pizarro 2007), France (Boudoint et al. 1953, Thiollay 1968, Choussy 1973, Malafosse & Malafosse 2018), Greece (Vlachos & Papageorgiou 1994, Bakaloudis et al. 1998, Bakaloudis & Vlachos 2011), Belarus (Ivanovsky 1992), Hungary (Becsy 1971), Germany (Reichholf 1988) and Italy (Petretti 1988, Campora & Alberti 1997). In Israel, a population of Short-toed Eagles was found to feed mainly on rodents hunted in cultivated areas (Darawshi 2017). In the stomachs of 50% (n = 14) of the drowned individuals recovered from the Strait of Gibraltar or killed by wind turbines, remains of invertebrates were found (Yáñez et al. 2013). In Italy, studies of this kind have been conducted only in the northern Alps and Apennines (Bruno & Perco 1980, Cecco 2003, Campora & Cattaneo 2006, Baghino et al. 2009) and in central Italy (Petretti 1988, 1995, unpublished data).

The present study has the following aims to: i) define the trophic spectrum of the Short-toed Eagle in Tolfa Mountains and compare it with the results of previous studies made in the same study area (Petretti, 1988). No major changes in diet composition are expected since the landscape mosaic has remained relatively unchanged over the past few decades; ii) compare the trophic spectra of adults and nestlings for which we do not made predictions because previous studies have indicated that the diet composition of the two age groups may be different or quite similar depending on the land use context (Gil & Pleguezelos 2001, Bakaloudis & Vlachos 2011); iii) track the prey delivery rate at nest throughout the daily activity; iv) compare the trophic spectrum of the observed Short-toed Eagle populations with that of other populations from Italy and Europe. Comparable results with other Italian populations are expected, assuming a qualitatively similar availability of prey in the environment.

MATERIALS AND METHODS

Study area

The study area is located in the Tolfa Mountains (11°58’15.6” E, 42°09’00.0” N), coinciding with the

Special Protection Area "Tolfetano-Cerite-Manziate District" (SPA IT6030005) designated in 1995 by the Italian National Authority (Ministry of Environment). The area (676 km^2) is located in the north-western part of the Latium Region (Central Italy) and it ranges from the Tyrrhenian coast to about 25 km inland being characterized by a central relief of volcanic origin (up to 633 m a.s.l.) surrounded by lower sedimentary formations. The hilly landscape is characterised by a dense hydrographic network of intermittent or ephemeral streams flowing either directly into the sea or into the river Mignone, which runs throughout the eastern and northern sectors of the study area. The land cover is composed mainly of farmland (314 km^2, 46.5%) and broad-leaved woodland (243 km^2, 35.9%), followed by shrubland (85 km^2, 12.6%), natural grassland (18 km^2, 2.6%), sparsely vegetated areas (15 km^2, 2.3%) and urban areas (0.4 km^2, 0.1%) (European Union, 2018). The extent of urban areas is probably underestimated, due to the rapid increase in building activities leading to changes in land use from agricultural to residential. Extensive cultivation (wheat, corn) covers 87% of farmland, while vineyards, fruit trees and gardens cover most of the remaining agricultural area. Most of the woodlands are dominated by Turkey Oak *Quercus cerris*, sometimes in association with Holm Oak *Quercus ilex* or Downy Oak *Quercus pubescens* (ARP 2010). Except for small portions of ancient forest and neglected coppice (woodlots left unmanaged), forested areas are managed for firewood production by stool shoot regeneration (coppice system) on a 20-30 yr rotation basis, where single mature trees are kept in the next rotation as seed bearers. Wooded areas form a mosaic with shrubs and grasslands (24% of the study area) where extensive livestock farming (mainly cattle, horses and donkeys, with a few sheep, but only in open areas) is the main productive activity.

Sampling methods

The diet of the Short-toed Eagle was studied during the breeding seasons 2020-2021. In order to analyse the species diet we used two methods: camera trapping of hunted prey and analysis of pellets and prey remains. For the Short-toed Eagle the first method is more effective, since the recovery of intact remains is very difficult (Campora & Alberti 1997). Here, the trophic spectrum of adults and juveniles was deduced both from analysis of pellets and remains collected under perches, in the nests and from camera trapping at the nest. The prey delivery rate at nest was deducted exclusively by camera trapping.

Camera trapping

We analysed images from three nests obtained with the camera trapping technique. Through this method it was possible to record each single prey delivery and the time it took place. The camera traps were installed on the nests of three different pairs: nest 1 was monitored between the 14^{th}-29^{th} of July 2020 using a Blaze Video Advanced 262 camera trap, with 64 GB SD card; for nest 2 we used a Browning BTC-8E camera trap, with 128 GB SD card, mounted on 28^{th} February 2021 at 1.75 m from the nest. Installation period: 1^{st} March - 31^{st} August 2021; in nest 3 we employed a Browning BTC-8E camera trap, with 128 GB SD card, mounted on 28^{th} February 2021 at 8 m from the nest. Installation: 1^{st} March - 31^{st} August 2021. In nest 2 and 3, the use of a camera-trap with large capacity memory card as well as an additional set of batteries made possible to replace card and batteries only in the first ten days of July, when the young was over 30 days old thus reducing the risk of disturbing the nestings. Camera traps 2 and 3 were removed once the nestlings had fledged. In the case of adults, only the images obtained at the nest before hatching (27^{th} May and 2^{nd} June) were considered as they were certainly not intended for nestlings. The photo-trapped prey identification was based on the reference literature (Fig. 1) (Di Nicola 2019, Di Nicola et al. 2021).

Figure 1. Example of images obtained from camera traps of Short-toed Eagles in the nest with prey: adult *Hierophis viridiflavus* (A); young *Elaphe quatuorlineata* (B); adult *Natrix helvetica* (C); adult *Vipera aspis* (D).

Prey remains analysis

We identified prey items also by collection and analysis of the prey remains. Prey fragments and pellets were taken from five nests (including those equipped with camera traps) and three roosts. To minimize nesting disturbance, roosts were visited only 3 times, between 22nd of June and 31st of August 2021. In order to avoid double counts at the camera trapped nests, only the prey types not previously detected by the photos were considered. The samples were stored in 75% ethanol and then analysed in the laboratory using a stereoscope (Optika SFX-34 10-30X), with the support of specific literature (Cecco 2003, Di Nicola et al. 2021) (Fig. 2). The identification of each prey was made, where possible, at the species level and, in the case of remains that did not allow such resolution, at a higher taxonomic level.

Statistical analysis

We calculated niche breadth using the Levins's standardized index (BA) (Hurlbert 1978, Bakaloudis & Vlachos 2011, Faraone et al. 2021) with the formula:

$$BA = [(1 / \Sigma pi2) - 1] / (N - 1)$$

where pi is the proportion of the ith prey and N is the number of prey types. BA ranges from 0, when only one type of prey occurs, to 1 when all categories of prey are equally divided. We calculated BA only on the basis of snake species in the diet composition, unless otherwise specified.

We calculated prey delivery rate at nest as the percentage of frequency delivery event for each of the thirteen one-hour intervals between 6:00 am and 7:00 pm (activity time range). Since our field observations showed that only few minutes passed between the capture of the prey and its delivery to the

Figure 2. Example of prey remains analysed in the laboratory: dorsal scales of adult *Hierophis viridiflavus* (A); dorsal scales of adult *Natrix helvetica* (B); dorsal scales of adult *Podarcis muralis* (C); skin of adult Common *Bufo bufo* (D). Dimensional reference: each notch equals one millimetre.

nest, we assumed that the delivery time substantially corresponds to the moment of capture. We also obtained mean, standard deviation and range values [reported as = X ± SD, (min-max), n] of the number of preys delivered at the nest on daily basis.

We used a χ^2 test to compare differences in diet composition in terms of prey frequency. In inter-population comparisons (nestlings vs adults; current vs previous data) we calculated χ^2 in a contingency table considering only items determined at a specific level, assuming the same qualitative availability of the prey in the study area. Between populations comparisons of prey composition was done only on the basis of seven main prey categories (i.e., snakes, lizards, tortoises, amphibian, mammals, birds, insects), assuming that the specific composition of diet in each country was qualitatively different. Alpha level was set at 0.05.

RESULTS

A total of 247 prey items were identified, of which 223 from image analysis and 24 from remains and pellets. 85% (n = 211) of the total items were identified at species level, otherwise they were identified at the genus (0.8%, n = 2), family (2.8%, n = 7), suborder (9.7%, n = 24), order (0.4%, n = 1), and class (0.8%, n = 2) level. 71.6% of the snakes identified at the genus or species level (n = 201) showed adult morphology and coloration, except the Four-lined Snakes *Elaphe quatuorlineata*, in which all the specimen (n = 10) had a colour pattern typical of juveniles and subadults. The overall diet composition obtained from phototrapping and remains analysis was pooled together since we did not find significant differences between their frequencies (χ^2 = 2.8, df = 1, P = 0.09) (Tab. 1).

Adults had a slightly broader feeding niche (BA = 0.13) than nestlings (BA = 0.08), however we did not detect significant differences in prey composition between the two age classes (χ^2 = 4.2, df = 4, P = 0.38, Tab. 1). Prey delivery rate at nest increased towards the central hours of the day with a peak in the time interval between 10:00 am and 11:00 am and slowly decreased in the subsequent hours (Fig. 3). The mean daily delivery rate was of 1.6 ± 0.8 (1-4) prey per nest.

Table 1. Diet composition of the Short-toed Eagle population under study. Percentages (%) are calculated on the total prey items (n). Und = Unidentified.

	Overall diet		**Nestling Diet**		**Adult Diet**	
Prey	**n = 247**	**%**	**n = 160**	**%**	**n = 59**	**%**
Tot. Reptiles	**241**	**97.6**	**157**	**98.1**	**59**	**100.0**
Und. Reptilia	1	0.4				
Tot. Snakes	**231**	**93.5**	**150**	**93.8**	**58**	**98.3**
Und. Ophidia	24	9.7	17	10.6	6	10.2
Tot. Colubridae	**198**	**80.2**	**129**	**80.6**	**47**	**79.7**
Und. Colubridae	6	2.4	3	1.9	3	5.1
Hierophis viridiflavus	166	67.2	109	68.1	40	67.8
Elaphe quatuorlineata	10	4.0	7	4.4	2	3.4
Natrix helvetica	12	4.9	7	4.4	2	3.4
Natrix tessellata	3	1.2	3	1.9		
Natrix sp.	1	0.4				
Tot. Viperidae	**9**	**3.6**	**4**	**2.5**	**5**	**8.5**
Vipera aspis	9	3.6	4	2.5	5	8.5
Tot. Sauria	**10**	**4.0**	**7**	**4.4**	**1**	**1.7**
Und. Lacertidae	1	0.4	1	0.6		
Podarcis muralis	2	0.8				
Lacerta bilineata	6	2.4	5	3.1	1	1.7
Anguis veronensis	1	0.4	1	0.6		
Tot. Amphibia	**2**	**0.8**	**2**	**1.3**		
Bufo bufo	2	0.8	2	1.3		
Tot. Mammalia	**2**	**0.8**	**1**	**0.6**		
Und. Mammalia	1	0.4				
Apodemus sp.	1	0.4	1	0.6		
Tot. Arthropoda	**1**	**0.4**				
Lepidoptera larvae	1	0.4				

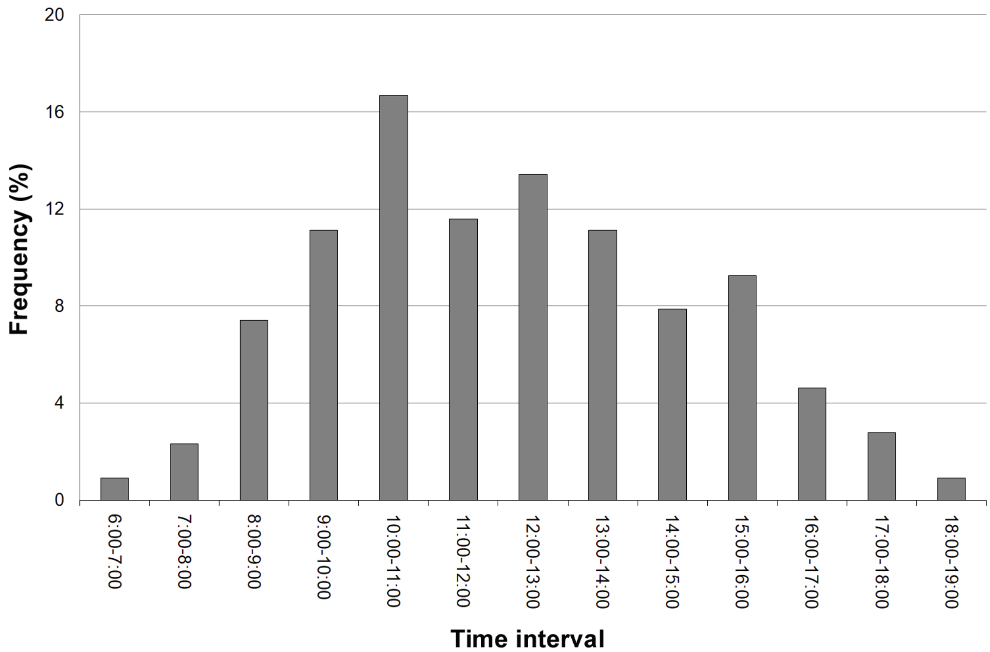

Figure 3. Prey deliveries (grey bars) to the nest by Short-toed Eagles during each of the thirteen 1-h intervals throughout a day (prey deliveries = 216: days = 150).

When we compared the diet composition of the studied population (2020 and 2021) with that characterised by Petretti (1988) between 1980 and 1985 (Fig. 4) we found that in the past, this Short-toed Eagle population had a broader diet composition (BA = 0.29) than today (BA = 0.11). Although, prey richness has not substantially changed over time, the frequencies of delivered prey did thus determining a significant difference between the trophic spectra calculated for the two time periods (χ^2 = 21.7, df = 7, P = 0.003).

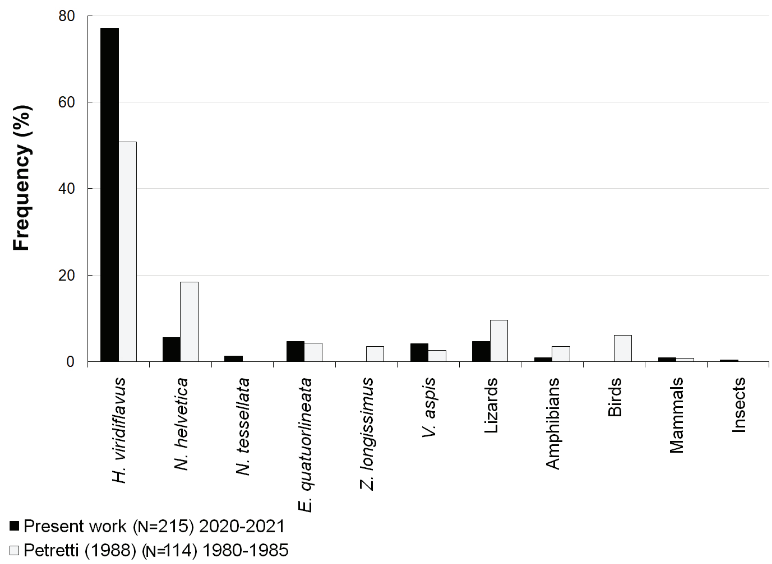

Figure 4. Comparison of prey spectrum of Short-toed Eagles in the Tolfa Mountains between two different periods. The taxonomic resolution has been reported at species level only for snakes.

Finally, when we compared our results with those obtained from other European populations, we found that all Short-toed Eagle populations had a prominent snake-based diet where all other prey types appeared only occasionally showing very low frequencies of occurrence (Fig. 5). Moreover, niche breadths (BA) were comparable among populations (range: 0.22-0.46) being in general wider compared to the value obtained here for the studied population (Tab. 2).

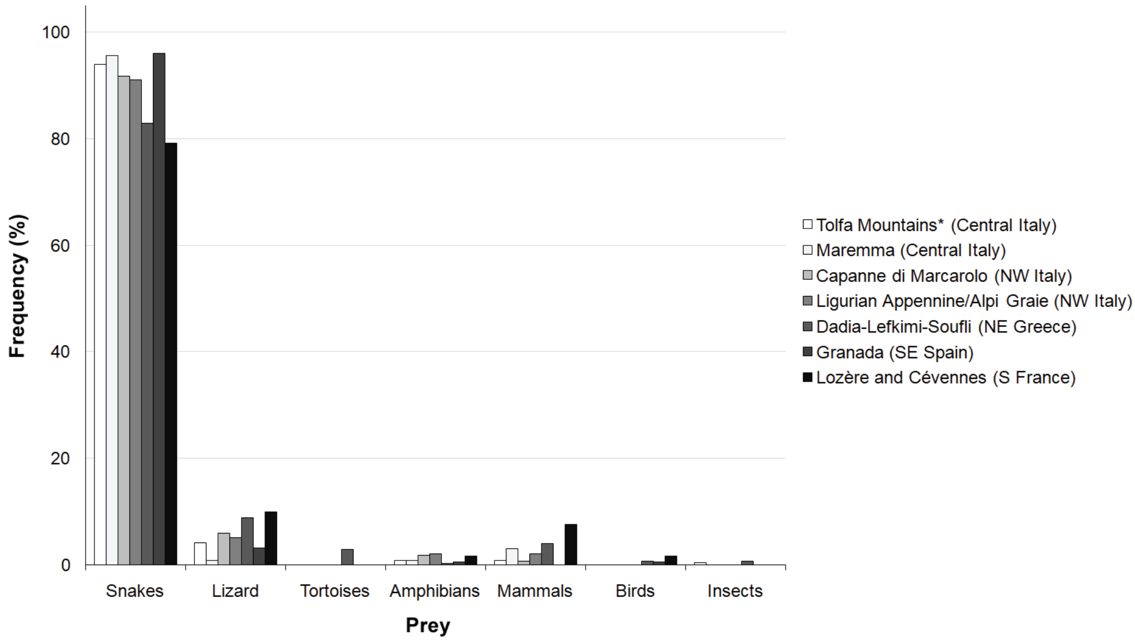

Figure 5. Breeding season variation in diet composition of Short-toed Eagle populations from different countries. Data marked with an asterisk are from the present work, the rest are obtained from: Petretti 1988, Campora & Alberti 1997, Cecco 2003, Bakaloudis & Vlachos 2011, Gil & Pleguezelos 2001, Malafosse & Malafosse 2018.

Table 2. Diet of different population compared to our data; niche breadth (BA) values are deduced from the showed references. Asterisk indicates that Grass Snake species are included in *Natrix* sp.

Country	Prey items	Time range	Snake species	BA	Reference
Central Italy	197	2020-2021	5	0.11	Present study
Central Italy	502	1980-1985	5	0.29	Petretti 1988
Central Italy	262	2007-2011	5*	0.32	Petretti unpublished data
NW Italy	175	1991-1996	6	0.32	Campora & Alberti 1997
NW Italy	206	1991-2002	7	0.22	Cecco 2003
SE Spain	214	1996-1997	4	0.37	Gil & Pleguezelos 2001
NE Greece	290	1996-1998	6	0.35	Bakaloudis & Vlachos 2011
S France	235	1998-2018	8	0.46	Malafosse & Malafosse 2018

DISCUSSION

Our data confirm that the Short-toed Eagle is a raptor highly specialized in the capture of reptiles as indicated by previous studies (Boudoint et al. 1953, Thiollay 1968, Becsy 1971, Amores & Franco 1981, Petretti 1988, Vlachos & Papageorgiou 1994, Bakaloudis et al. 1998, Gil & Pleguezuelos 2001, Moreno-Rueda & Pizarro 2007). The prey composition of its diet is clearly dominated by snakes, which made up 94% of all identified prey items (Tab. 1). We identified five snake species out of a total of eight present in the study area (Bruno 1977; Bologna et al. 2007; Di Nicola et al. 2021) being the remaining three, the Smooth Snake *Coronella austriaca*, the Southern Smooth Snake *Coronella girondica* and the Aesculapian Snake *Zamenis longissimus*. The absence of these three species in the diet of our studied population could be due to their elusive and crepuscular habits or to their lower thermophilicity (see Corti et al. 2011, Di Nicola et al. 2021) when compared to the other snake species preyed by the Short-toed Eagle. The ecological needs of these three snakes can limit their diurnal activity or can confine them into shady biotopes with thick vegetation cover thus reducing the risk of predation by hunting birds as the Short-toed Eagle.

Most of the preyed snakes were adult individuals as observed also in other Short-toed Eagle populations (Petretti 1988, Bakaloudis et al. 1998, Gil & Pleguezuelos 2001). This does not happen in the Four-lined Snake of which mainly young and sub-adult individuals are preyed. However, this species is larger in size (Di Nicola et al. 2021) therefore, immature individuals fall within the prey size usually selected by the Short-toed Eagle (see Petretti 1988, Bakaloudis et al. 1998, Gil & Pleguezuelos 2001). The Asp *Vipera aspis* is marginally predated (3.6% of the overall diet) despite being a very abundant species in the study area (Filippi & Luiselli 2006). This is likely due to its average size in terms of snout-to-vent length (Zuffi et al. 2009), that is not included in the most frequently selected prey size range (Petretti 1988, Bakaloudis et al. 1998). The Asp, however, is sometimes a crucial prey for Short-toed Eagle as for example occurs in Switzerland (Maumary et al. 2013). This could depend on the local species composition of the ophidian community.

The Western Whip Snake *Hierophis viridiflavus* is the most abundant species in the diet, alone constituting 83.0% of all snakes determined at the specific level (n = 200). It is a generalist, extremely adaptable species that can occur in high densities (Vanni & Zuffi 2011) and is considered to be the most widespread snake in the Italian territory (Vanni & Nistri 2006). The Western Whip Snake is an elective prey for the Short-toed Eagle, probably due to its high availability in the environment. Its preference for open areas rich in ecotones (Vanni & Zuffi 2011) makes it vulnerable to Short-toed Eagle predation. Furthermore, the average size in terms of snout-to-vent length of the Western Whip Snake (Vanni & Zuffi 2011) is included in the prey size ranges positively selected from this hunting bird in various snake species (Petretti 1988, Bakaloudis et al. 1998, Gil & Pleguezuelos 2001). The Western Whip Snake is the main prey of Short-toed Eagle in terms of relative frequency, when it is present (Petretti 1988 unpublished data, Campora & Alberti 1997, Gil & Pleguezelos 2001, Cecco 2003, Malafosse & Malafosse 2018).

In this species, diet composition among age classes appears to be more variable at inter-population level. In some cases, nestlings consume more small prey such as lizards than adults (Bakaloudis et al. 1998), while in other cases (Gil & Pleguezuelos 2001), as well as in the present study, there are no substantial differences in diet between the two age classes.

Our data on prey delivery rate at nest through daytime indicate a clear unimodal pattern with a peak between 10:00 and 11:00 am, exactly as observed by Bakaloudis & Vlachos (2011) in North-East Greece, where however recorded at more prominent peak (≈ 30% vs 16.7%). This could indicate a shorter duration of the daily hunting activity in the latter case. The daily variation detected by Petretti (1988) for the Short-toed Eagle in our same study area, during the period 1980-1985, has instead a more irregular trend with a peak in the 12:00 am – 1:00 pm interval, following an apparent suspension in the delivery activity between 11:00 and 12:00 am. The delivery rate to the nestlings is 1.6 prey per day, a value similar to that calculated for the same area by Petretti (1988) (1.8 prey per day) and higher than that recorded by Bakaloudis & Vlachos (2001) (1.1 prey per day) in Greece.

We found a significant variation in diet composition by comparing the data collected between 1980 and 1985 (Petretti 1988) and those between 2020 and 2021 (present study) in the same area. We did not find strong qualitative variations in the diet composition, but we observed variations in the frequencies of the prey types, which caused a decrease in the BA value over time. This change was probably due to the increased dominance of the Western Whip Snake among the predated snakes. In fact, during the first period (1980-1985) the relative frequency of this prey species (50.9%) was lower than in the second one (2020-2021) (77.2%) while the opposite occurred for the Grass Snake *Natrix helvetica* that was predated more frequently in the first period (18.4%) than in the second one (5.6%). It is interesting to note that this pattern is in line with the results of a long-term study on the ophidian community of the Tolfa Mountains carried out by Filippi & Luiselli (2006). Between 1990 and 2003 they observed an increase in the abundance of the Western Whip Snake and a specular decrease in other snake species including the Grass Snake. Furthermore, Capula et al. (2016) in the same geographical area and during the period 1990-2014, recorded a progressive increase in the predatory activity and prey diversity of the Western Whip Snake, also highlighting a positive relationship with the increase of mean annual temperature. Climate change (Capula et al. 2016) and some human activities (Filippi & Luiselli 2006) could so favour the increase of thermophilic and generalist species such as the Western Whip Snake and the decrease of other species with a narrower niche. These processes may have locally contributed to the shrinking of Short-toed Eagle's diet breadth in the Tolfa Mountains.

Our comparison between populations confirms the highly specialized snake-based diet of the Short-toed Eagle: all populations show a similar diet composition with respect to the prey types considered (Fig. 5). Our data from the Tolfa Mountains show values of niche breadth clearly narrower than those calculated for the other populations (Tab. 2). Some of the geographic areas examined have qualitatively different ophidian communities which probably influence the Short-toed Eagle's diet composition and breadth. In fact, the wider niche breadths are recorded in geographical areas such as France (Malafosse & Malafosse 2018), Spain (Gil & Pleguezelos 2001) and Greece (Bakaloudis & Vlachos 2011) which have a greater abundance of thermophilic snake species reaching medium to large size and more frequently associated with open habitat (Bakaloudis et al. 1998, Geniez 2015).

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