

Factors affecting the diet of Peregrine Falcon in Italy

SALVATORE BONDÌ, ENRICO GUZZO, ELISA VITALE, ALESSANDRO BARAGONA,
DESIRÉE GRANCAGNOLO, MAURIZIO SARA*

*Dipartimento di Scienze e Tecnologie Biologiche, Chimiche e Farmaceutiche, Sezione di Biologia Animale,
Università di Palermo - Via Archirafi 18, 90123 Palermo (Italy)*

*Corresponding author: maurizio.sara@unipa.it

Abstract – The diet of top predators can provide useful information on phenology and abundance of their prey. The cosmopolitan and specialist Peregrine Falcon *Falco peregrinus* is an ideal model to assess whether food changes have occurred in the long-term. In this contribution, we reviewed all available literature on Peregrine Falcon diet in Italy which contained 11 detailed datasets useful for our review, and also included analysis of pellets, collected at three breeding sites of Sicily during 2014 and 2015. These data allowed us to shed light on the Peregrine Falcon's diet over the last forty years (1978-2015). We calculated the numerical and biomass percentage of the resident and not-resident prey proportions, as well as the trophic diversity of diet in each site using the Simpson diversity index. To describe the Peregrine Falcon food niche and investigate whether year, habitat and latitude effects existed in its diet, we used a 2nd-degree factorial ANOVA. Over 1,550 prey, 110 bird species accounted for 98.58% of frequency and 99.79% of biomass. Modelling showed a year effect, with the quota and biomass of resident prey species increasing across the forty years of the study period, in a way complementary to the decrease of the quota and biomass of not-resident prey species. Conversely, habitat and latitude predicted significantly trophic diversity that was larger in rural than urban habitats, and at northern than southern latitudes. The strong numerical and biomass decrease of not-resident prey in the trophic niche of Peregrine Falcon in Italy could be related to the negative population trends of both migratory and summer-breeder farmland species. Actually the bulk of prey of the Peregrine Falcon in Italy is formed by a restricted group of resident Corvidae and Columbidae, which have remarkably increased in the last years. This could trigger more dependence on resident prey in the long term, making the Peregrine Falcons more vulnerable to control programs or eradication of specific prey populations or exposing them locally to high risk of infections (chlamydiosis, avian trichomiasis) transferred by feral species.

Key-words: Dietary change, *Falco peregrinus*, migratory birds, pellet analysis, trophic niche.

INTRODUCTION

During last decades, climate influenced population trends of European migrant birds chiefly modifying their timing of spring arrivals from wintering grounds (Pearce-Higgins & Green 2014), contracting their migratory distances (Visser *et al.* 2009, Morganti 2015) and shifting their geographical distributions (Donnelly *et al.* 2009, Chambert *et al.* 2015). The consequent variation in composition of avian communities could likely affect ecosystem functioning and prey-predator equilibrium, because predators are highly sensitive to changes in the availability of their prey and to altered prey assemblages (Newton 1979). Population trends of prey species, resulting from human overhunting, land use or climate change, may reflect changes in the diet of their predators (Green *et al.* 2015, Roulin 2015). Indeed, long-term studies of dietary change can provide valuable insight into the nature of environmental shifts across the habitats in which top predators forage.

Birds of prey shift their diet both between seasons of the year (Yanez *et al.* 2013; Bondi *et al.* 2014) and among years (Robinson *et al.* 2015). In the long-term, they can also respond to changes in density and availability of their usual prey moving to better and richer habitats (e.g. Millon *et al.* 2009) or choosing easier and plentiful new prey (Steenhof *et al.* 1988, Buij *et al.* 2013). Hitherto, a few studies have suggested that avian predators could show a dietary change in response of climate change which in turn affected their prey species (e.g. Millon *et al.* 2009, Roulin 2015).

Peregrine Falcon is a cosmopolitan raptor (Ferguson-Lee & Christie 2001) and it is an ideal model to assess whether such changes have occurred in the long-term. The Peregrine Falcon is sedentary and quite common along the Italian peninsula (826-1048 breeding pairs according to Allavena & Brunelli 2003), where it breeds in diverse habitats and altitudes (Bricchetti & Fracasso 2003-2015). The Peregrine Falcons prey almost exclusively upon birds

(White *et al.* 2013) and the period of the highest energy demand of the Peregrine Falcon chicks, just before their fledging event in April-May, coincides with the spring migration of numerous potential prey species (White *et al.* 2013). Indeed some breeding pairs, especially in the circum-Italian islands and along migration bottle-necks across the Mediterranean, concentrate their hunting on migrant birds (Baccetti *et al.* 1984, Allavena & Brunelli 2003).

In this contribution we reviewed all the available literature reporting data on the diet of Peregrine Falcon in Italy and we tested whether the falcon diet changed across time, habitat and latitude of Italy.

MATERIALS AND METHODS

We collected and revised all available literature on Peregrine Falcon diet along the Italian territory (Massa 1981, Schenk *et al.* 1983, Baccetti *et al.* 1984, Mocchi Demartis & Murgia 1986, Serra *et al.* 2001, Ceccarelli *et al.* 2003, Proietti *et al.* 2004, Rizzoli *et al.* 2005, Leonardi & Mannino 2007, Fracasso *et al.* 2009, Fraissinet & De Rosa 2010, Verdari 2011) and we found only 11 detailed datasets, as some contributes (Massa 1981, Serra *et al.* 2001) provided aggregated data not useful for analysis. Moreover, we implemented the database with three Sicilian sites, where pellets were collected and analyzed during 2014 and 2015. We treated together pellets and food remains (feathers, carcasses, whole bones and bone fragments), since their combined analysis has been recommended, as an accurate method, for evaluate the diet of the Peregrine Falcon (Oro & Tella 1995). Pellets coming from the three Sicilian sites were put in separate plastic bags to avoid mixing the material, and then dried in laboratory in order to prevent organic decay. Prey were identified, when possible at the species or genus level, by comparison with bird and anatomical collections hold in the Zoological Museum 'Pietro Doderlein' of Palermo University and by comparative anatomical manuals (Cole & Serjeantson 1996). Feathers and other remains allowed detecting the presence of both wild Rock Doves *Columba livia* and Feral Pigeons *C. livia* f. *domestica*. Nonetheless, we considered together these two taxa that actually form mixed flocks and colonies (AA. VV. 2008) and used their median body weight (cf. Brichetti & Fracasso 2003-2015) to assess the biomass contribution of the two species. We excluded from our analysis all remains and fragments identified at taxonomic ranks (e.g. Passeriformes) higher than genus. In addition, we listed Mammal species found in the datasets, but we excluded them from further analyses because we were interested in

modelling the effect of year and other predictors on the resident versus the not-resident quota of bird preyed upon. The Italian Bird check-list (Fracasso *et al.* 2009) was used as taxonomical reference and species coming from the 14 datasets were divided into "resident" and "not-resident" according to their phenology in the studied areas (e.g. the Common Starling was treated as resident in continental Italy and as not-resident in Sicily; cf. Brichetti & Fracasso 2003-2015). Accordingly, body weight of prey species were first obtained by pertinent literature (AA.VV. 2008, Brichetti & Fracasso 2003-2015) and then standardized (Snow & Perrins 1998), in order to obtain equal values for the 14 datasets. Per every dataset we calculated the numerical (PFI, Percentage Frequency of Items) and biomass quotas (PBI, Percentage Biomass of Items) of the resident and not-resident prey proportions. Besides, we calculated the trophic diversity of diet at each site using the Simpson diversity index (1/D). We used PFI, PBI of both resident and not-resident prey and trophic diversity as response variables to describe the Peregrine Falcon food niche and investigate whether year, habitat and latitude effects occurred in its diet. Due to the limited sample of datasets, the only way to model changes in the response variables was to choose some macro-variables and categorize them in meaningful groups, even if some (i.e. latitude and year) are routinely treated as continuous variables (Sokal & Rohlf 1994). Therefore the 14 datasets were divided according to: i) latitude [2 levels: group 1 from the Alps to northern Lazio (4693592 m N; 308890 m E); group 2 from southern Lazio (4633321 m N; 339067 m E) to Sicily], ii) habitat (2 levels: urban and rural), iii) year of collection (2 levels: group 1 before 2000, group 2 after 2000). We performed a 2nd-degree factorial ANOVA for each response variable and the related set of categorical predictors. The 2nd-degree factorial design allowed checking whether also interactions between predictors (i.e. 'latitude x habitat', 'latitude x year' and 'habitat x year') could have a meaningful influence on the response variables. The effect size (partial eta-squared and observed power) of the factorial design took in account the amount of information in the dependent variables that is explained by each predictor and the relative power of the tested effects. Statistical significance was set at $P < 0.05$, and means \pm standard errors (SE) have been reported. Factorial ANOVA and other statistics (Mann-Whitney U test, linear regression) pertinent to the analyses were computed in STATISTICA 10.0 (Statsoft inc.). Because the PFI and PBI response variables are paired and complementary (e.g. PFI of not-resident is equal to $1 - \text{PFI of resident}$, or viceversa) statistics values (e.g. Z, F) are equal for every pair.

RESULTS

The analysis of pellets and prey remains in the 14 datasets of Italy yielded 1,550 identified prey of birds and mammals (Tab. 1). 1,528 birds belonging to 110 different species and 41 families form the bulk of prey yielding the 98.58% of PFI and the 99.79% of PBI. Four new species (in bold in Tab. 1) have been recorded for the first time in the Peregrine Falcon diet, during pellet analyses of Sicilian sites. Nonetheless, a single family, the Columbidae, contributes the highest numerical (31%) and biomass (56%) percentage of prey. Predation upon mammals is negligible both in terms of PFI (1.42%) and PBI (0.21%), and it is limited to bats if we exclude one exceptional case upon *Rattus norvegicus*. The average prey weight is 136.1 ± 16.4 grams and ranged from the 7-9 grams of Vespertilionidae bats and *Phylloscopus* warblers, to the 1,065 grams of *Tetrao tetrix* (Tab. 1). The average numerical and biomass percentages of the avian component of diet divided per the resident and not-resident species has been reported in Tab. 2, together with the preliminary Mann-Whitney U tests on the median values.

Results of 2nd-degree factorial ANOVA testing the effects of year, latitude and habitat on both the resident and not-resident quota of prey and trophic diversity have been reported in Tab. 3. Only year predicted changes in the numerical percentage of both resident and not-resident species, accounting for the 42% of variability contained in these response variables. Year has a power of 57% in explaining alone the information contained in the 14 PFI values. Likewise it occurs for the biomass percentage of both the resident and not-resident species, with a 40% of variability and a related 52% of power size. Taking into account the meaningful power of the effect year, we fitted a linear regression of both PFI and PBI with this predictor. Definitely, year had a positive effect on both the PFI and PBI of resident preys, which increased from 1978 to 2015 in a way complementary to the decrease of the not-resident quota of prey (Fig. 1).

Instead of year, the 2nd-degree factorial ANOVA predicted the significant effect of habitat and secondarily of latitude on trophic diversity of Peregrine Falcon (Tab. 3).

DISCUSSION

Diet studies of raptors present numerous methodological challenges, and the use of new tools like trail-cameras joined with the statistical treatment of unidentified prey provided advances in the field (Robinson *et al.* 2015). Molecular techniques using DNA bar-coding, actually re-

stricted to the study of frugivorous diets (e.g. Galimberti *et al.* 2016), could represent a further progress also in the study of raptor food niches. In an evaluation of pros and cons between cameras and traditional pellet analysis using the bird-eating Northern Goshawk *Accipiter gentilis*, Garcia-Salgado *et al.* (2015) concluded that the sensitivity of each method depended on prey size and taxonomic group, with no method providing unbiased estimates for all prey sizes and types. Despite the potential biases of using traditional pellet and remain analysis, this latter method is the only available in hand when the aim of the study is the comparison of actual and past data of raptor diets.

We were able to review and summarize the diet of the Peregrine Falcon in Italy across forty years and, despite the potential underrepresentation of preyed taxa connected to pellet analysis, and the broad categorization of effects that the low number of studies (14) and prey (1,550) allowed, we have confirmed the striking ornithophagous habits of the species which relies almost exclusively upon birds, particularly Columbidae from North Italy to Sicily. Like elsewhere within the Peregrine Falcon's large distribution, avian prey species span over a large range of sizes, while mammals are only occasionally preyed upon (see White *et al.* 2013 and references therein).

More interestingly, when checking the trophic habits of the Peregrine Falcon in the long-term, we were able to rule out the effects of the latitude and habitat of the various areas of study, and to find that only time (i.e. the year of pellet collection) influenced the variation of diet in the considered sample. In the last forty years, the numerical and biomass percentages of resident species has significantly increased whereas the complementary quota of not-resident species has decreased.

Recent studies (Morrison *et al.* 2013, Pearce-Higgins *et al.* 2015) have reported negative population trends of migratory birds, especially regards to long-distance species, in Europe. Global changes (i.e. land use and climate changes) have a direct impact on population dynamics and the abundance of species (McCarty 2001, Walther *et al.* 2002). Interestingly, the Farmland Bird Index (Gregory *et al.* 2005) in Italy during the 2000-2013 (Rete Rurale Nazionale & LIPU 2014) recorded a general decrease (-17.8%) of farmland species. More specifically, several summer or partially migrant breeding species decreased (e.g. Short-toed Lark *Calandrella brachydactyla*, Skylark *Alauda arvensis*, Barn Swallow *Hirundo rustica*) while most of resident Corvidae and Columbidae have remarkably increased, likely due to anthropogenic impacts such as habitat fragmentation, agriculture intensification and land abandonment. It is thus likely that avian community composition has been changing at both large and local scale, and the im-

Table 1. Frequency of occurrence (PFI) and contribution in terms of ingested biomass (PBI) of prey items found in pellets and prey remains of Peregrine Falcon in Italy. Prey species found in pellet analyses of 2014-2015, and that are the first record in the Italian diet have been reported in bold.

FAMILY	SPECIES	<i>n</i>	PFI	Biomass (gr)	PBI
Anatidae (<i>n</i> = 1)	<i>Anas crecca</i>	2	0.13	660	0.27
Phasianidae (<i>n</i> = 2)	<i>Alectoris chukar</i>	1	0.06	550	0.23
	<i>Coturnix coturnix</i>	75	4.84	7500	3.12
Tetraonidae (<i>n</i> = 1)	<i>Tetrao tetrax</i>	1	0.06	1065	0.44
Ardeidae (<i>n</i> = 2)	<i>Egretta garzetta</i>	1	0.06	450	0.19
	<i>Ixobrychus minutus</i>	4	0.26	600	0.25
Podicipedidae (<i>n</i> = 2)	<i>Podiceps nigricollis</i>	9	0.58	2790	1.16
	<i>Tachybaptus ruficollis</i>	8	0.52	1120	0.47
Accipitride (<i>n</i> = 3)	<i>Accipiter nisus</i>	2	0.13	410	0.17
	<i>Circus pygargus</i>	1	0.06	325	0.14
	<i>Circus sp.</i>	3	0.19	1191	0.50
	<i>Pernis apivorus</i>	1	0.06	730	0.30
Falconidae (<i>n</i> = 1)	<i>Falco tinnunculus</i>	7	0.45	1435	0.60
Rallidae (<i>n</i> = 3)	<i>Fulica atra</i>	2	0.13	1600	0.67
	<i>Gallinula chloropus</i>	32	2.06	10240	4.26
	<i>Rallus aquaticus</i>	9	0.58	1125	0.47
Charadriidae (<i>n</i> = 2)	<i>Pluvialis apricaria</i>	3	0.19	660	0.27
	<i>Vanellus vanellus</i>	13	0.84	2990	1.24
Laridae (<i>n</i> = 2)	<i>Chroicocephalus ridibundus</i>	6	0.39	1740	0.72
	<i>Larus fuscus</i>	1	0.06	830	0.34
Recurvirostridae (<i>n</i> = 1)	<i>Recurvirostra avosetta</i>	1	0.06	280	0.12
Scolopacidae (<i>n</i> = 6)	<i>Actitis hypoleucos</i>	1	0.06	50	0.02
	<i>Calidris alpina</i>	2	0.13	96	0.04
	<i>Gallinago gallinago</i>	1	0.06	110	0.05
	<i>Scolopax rusticola</i>	15	0.97	4200	1.75
	<i>Tringa glareola</i>	1	0.06	65	0.03
	<i>Tringa nebularia</i>	2	0.13	380	0.16
Sternidae (<i>n</i> = 2)	<i>Tringa sp.</i>	1	0.06	119	0.05
	<i>Chlidonias niger</i>	1	0.06	73	0.03
	<i>Sterna hirundo</i>	1	0.06	130	0.05
Columbidae (<i>n</i> = 5)	<i>Columba livia</i>	366	23.61	109800	45.64
	<i>Columba oenas</i>	3	0.19	900	0.37
	<i>Columba palumbus</i>	24	1.55	10800	4.49
	<i>Streptopelia decaocto</i>	25	1.61	5000	2.08
	<i>Streptopelia turtur</i>	62	4.00	8680	3.61
Psittacidae (<i>n</i> = 1)	<i>Melopsittacus undulatus</i>	1	0.06	35	0.01
Cuculidae (<i>n</i> = 1)	<i>Cuculus canorus</i>	13	0.84	1560	0.65
Strigidae (<i>n</i> = 4)	<i>Asio otus</i>	1	0.06	290	0.12
	<i>Athene noctua</i>	1	0.06	180	0.07
	<i>Otus scops</i>	8	0.52	720	0.30
	<i>Strix aluco</i>	1	0.06	470	0.20
Tytonidae (<i>n</i> = 1)	<i>Tyto alba</i>	2	0.13	600	0.25
Caprimulgidae (<i>n</i> = 1)	<i>Caprimulgus europaeus</i>	8	0.52	664	0.28
Apodidae (<i>n</i> = 2)	<i>Apus apus</i>	54	3.48	2376	0.99
	<i>Apus melba</i>	2	0.13	200	0.08
Alcedinidae (<i>n</i> = 1)	<i>Alcedo atthis</i>	1	0.06	40	0.02

continued

Factors affecting the diet of Peregrine Falcon in Italy

FAMILY	SPECIES	n	PFI	Biomass (gr)	PBI
Coraciidae (n = 1)	<i>Coracias garrulus</i>	1	0.06	140	0.06
Meropidae (n = 1)	<i>Merops apiaster</i>	1	0.06	61	0.03
Upupidae (n = 1)	<i>Upupa epops</i>	32	2.06	2176	0.90
Picidae (n = 3)	<i>Dendrocopos major</i>	4	0.26	152	0.06
	<i>Jynx torquilla</i>	4	0.26	340	0.14
	<i>Picus viridis</i>	5	0.32	950	0.39
Aegithalidae (n = 1)	<i>Aegithalos caudatus</i>	1	0.06	9	0.00
	<i>Alauda arvensis</i>	2	0.13	78	0.03
Alaudidae (n = 3)	<i>Galerida cristata</i>	4	0.26	184	0.08
	<i>Melanocorypha calandra</i>	1	0.06	60	0.02
Corvidae (n = 6)	<i>Corvus cornix</i>	13	0.84	6630	2.76
	<i>Corvus monedula</i>	5	0.32	1100	0.46
	<i>Garrulus glandarius</i>	15	0.97	2550	1.06
	<i>Pica pica</i>	12	0.77	2640	1.10
	<i>Pyrrhonorax graculus</i>	1	0.06	220	0.09
	<i>Pyrrhonorax pyrrhonorax</i>	1	0.06	310	0.13
Emberizidae (n = 3)	<i>Emberiza calandra</i>	5	0.32	235	0.10
	<i>Emberiza circlus</i>	16	1.03	400	0.17
	<i>Emberiza schloenicus</i>	1	0.06	14	0.01
Fringillidae (n = 8)	<i>Carduelis cannabina</i>	5	0.32	95	0.04
	<i>Carduelis carduelis</i>	54	3.48	918	0.38
	<i>Carduelis chloris</i>	21	1.35	588	0.24
	<i>Carduelis spinus</i>	2	0.13	30	0.01
	<i>Coccothraustes coccothraustes</i>	2	0.13	116	0.05
	<i>Fringilla coelebs</i>	24	1.55	576	0.24
	<i>Loxia curvirostra</i>	1	0.06	43	0.02
	<i>Serinus serinus</i>	5	0.32	65	0.03
Hirundinidae (n = 2)	<i>Hirundo rustica</i>	13	0.84	247	0.10
	<i>Ptyonoprogne rupestris</i>	6	0.39	144	0.06
Lanidae (n = 2)	<i>Lanius collurio</i>	3	0.19	90	0.04
	<i>Lanius senator</i>	1	0.06	35	0.01
Motacillidae (n = 3)	<i>Anthus trivialis</i>	4	0.26	96	0.04
	<i>Anthus sp.</i>	1	0.06	23	0.01
	<i>Motacilla alba</i>	10	0.65	210	0.09
	<i>Motacilla flava</i>	2	0.13	36	0.01
Muscicapidae (n = 2)	<i>Ficedula sp.</i>	1	0.06	13	0.01
	<i>Muscicapa striata</i>	2	0.13	34	0.01
Oriolidae (n = 1)	<i>Oriolus oriolus</i>	26	1.68	1768	0.73
Paridae (n = 2)	<i>Cyanistes caeruleus</i>	1	0.06	11	0.00
	<i>Parus major</i>	2	0.13	36	0.01
Passeridae (n = 3)	<i>Passer hispaniolensis</i>	16	1.03	464	0.19
	<i>Passer italiae</i>	33	2.13	924	0.38
	<i>Passer montanus</i>	12	0.77	288	0.12
	<i>Passer sp.</i>	5	0.32	145	0.06
Prunellidae (n = 1)	<i>Prunella collaris</i>	1	0.06	40	0.02
Sturnidae (n = 2)	<i>Sturnus unicolor</i>	40	2.58	3640	1.51
	<i>Sturnus vulgaris</i>	118	7.61	9204	3.83
Sylvidae (n = 8)	<i>Cisticola juncidis</i>	2	0.13	20	0.01
	<i>Phylloscopus collybita</i>	1	0.06	8	0.00

continued

FAMILY	SPECIES	<i>n</i>	PFI	Biomass (gr)	PBI
Turdidae (<i>n</i> = 13)	<i>Phylloscopus sibilatrix</i>	3	0.19	30	0.01
	<i>Phylloscopus sp.</i>	1	0.06	9	0.00
	<i>Sylvia atricapilla</i>	5	0.32	105	0.04
	<i>Sylvia borin</i>	2	0.13	38	0.02
	<i>Sylvia cantillans</i>	1	0.06	11	0.00
	<i>Sylvia conspicillata</i>	1	0.06	10	0.00
	<i>Sylvia melanocephala</i>	5	0.32	65	0.03
	<i>Sylvia sp.</i>	4	0.26	72	0.03
	<i>Erithacus rubecula</i>	4	0.26	72	0.03
	<i>Luscinia megarhynchos</i>	8	0.52	168	0.07
	<i>Monticola solitarius</i>	7	0.45	427	0.18
	<i>Oenanthe oenanthe</i>	6	0.39	144	0.06
	<i>Oenanthe sp.</i>	1	0.06	22	0.01
	<i>Phoenicurus ochruros</i>	3	0.19	48	0.02
	<i>Phoenicurus phoenicurus</i>	1	0.06	15	0.01
	<i>Saxicola rubetra</i>	2	0.13	34	0.01
	<i>Saxicola torquata</i>	3	0.19	45	0.02
	<i>Turdus iliacus</i>	1	0.06	63	0.03
	<i>Turdus merula</i>	67	4.32	6700	2.78
	<i>Turdus philomelos</i>	43	2.77	3569	1.48
<i>Turdus pilaris</i>	34	2.19	3400	1.41	
<i>Turdus viscivorus</i>	6	0.39	780	0.32	
<i>Turdus sp.</i>	3	0.19	282	0.12	
Total Birds		1528	98.58	240094	99.79
Vespertilionidae (<i>n</i> = 4)	<i>Epseticus serotinus</i>	2	0.13	48	0.02
	<i>Hypsugo savii</i>	7	0.45	49	0.02
	<i>Pipistrellus pipistrellus</i>	7	0.45	49	0.02
	<i>Pipistrellus kuhlii</i>	4	0.26	28	0.01
	<i>Pipistrellus pipistrellus/kuhlii</i>	1	0.06	7	0.00
Muridae (<i>n</i> = 1)	<i>Rattus norvegicus</i>	1	0.06	332	0.14
Total Mammals		22	1.42	513	0.21
Total prey		1550		240607	

pect of global change has been influencing also prey-predator relationships, allowing the detection of dietary shifting in Peregrines. If this would be the case, the Italian populations of Peregrine Falcon are opportunistically responding to climate and habitat deterioration by preying much more upon few resident and common species. These latter, i.e. Wild Rock and Feral Pigeon, Wood Pigeon *Columba palumbus*, Collared Dove *Streptopelia decaocto*, Hooded Crow *Corvus cornix*, Magpie *Pica pica*, already formed the bulk of their diet in the Italian peninsula and elsewhere in their range of distribution (Bricchetti & Fracasso 2006, Dawson et al. 2011, White et al. 2013). The positive population trends of such prey species, which are also the most

energetically rewarding ones (e.g. Rutz et al. 2006, Rutz 2012), and the contemporary decrease of small size prey, which instead demand high energy to be hunted (Thiollay, 1982), almost certainly play a role in the increase of Italian Peregrine Falcon population after the year 2000 (Allavena & Brunelli 2003). The decrease of the quota of small size and seasonally available species (e.g. Larks, Pipits, Common Dove, etc) should be recorded in the trophic diversity reduction. Our modeling revealed a strong habitat (rural vs urban) and latitude (north vs south) effect and a relatively less important effect of time in the case of trophic diversity. However, the only pre- and post-2000 comparison was available in Sicily, and recorded a remarkable reduction of

Table 2. Basic statistics (mean±SE) of the numerical occurrence (PFI), ingested biomass (PBI) and trophic diversity (Simpson 1/D index) of resident and not-resident prey items found in 14 datasets which recorded the diet of Peregrine Falcon in Italy. The significant Z values of Mann-Whitney U tests have been marked in bold.

Effect	Level of factor	n	PFI not-resident	PFI resident	PBI not-resident	PBI resident	Trophic diversity
Habitat	rural	7	47.95 ± 9.80	52.05 ± 9.80	32.90 ± 7.66	67.10 ± 7.66	10.58 ± 1.40
	urban	7	40.48 ± 10.96	59.52 ± 10.96	26.06 ± 9.64	73.94 ± 9.64	6.13 ± 0.93
	U-test		Z = 0.51 P = 0.61	Z = 0.51 P = 0.61	Z = 0.89 P = 0.37	Z = 0.89 P = 0.37	Z = 1.92 P = 0.05
Year	2000-15	9	32.22 ± 6.81	67.78 ± 6.81	19.72 ± 4.81	80.28 ± 4.81	7.50 ± 1.23
	1978-94	5	65.81 ± 10.73	34.19 ± 10.73	47.05 ± 11.10	52.95 ± 11.10	9.88 ± 1.75
	U-test		Z = 2.0 P = 0.04	Z = 2.0 P = 0.04	Z = 1.87 P = 0.06	Z = 1.87 P = 0.06	Z = 1.20 P = 0.23
Latitude	south	7	47.62 ± 10.13	52.38 ± 10.13	32.83 ± 9.74	67.17 ± 9.74	8.17 ± 1.14
	north	7	40.81 ± 10.69	59.19 ± 10.69	26.13 ± 7.54	73.87 ± 7.54	8.54 ± 1.78
	U-test		Z = 0.51 P = 0.61	Z = 0.51 P = 0.61	Z = 0.51 P = 0.61	Z = 0.51 P = 0.61	Z = 0.00 P = 1.0
Total		14	44.21 ± 7.14	55.79 ± 7.14	29.48 ± 5.99	70.52 ± 5.99	8.35 ± 1.02

Table 3. Result of 2nd-degree factorial ANOVA testing for the role of habitat (HAB), latitude (LAT) and year (YR) and of their interactions to predict the numerical (PFI) and biomass (PBI) percentage of resident and not-resident prey (A-D), and the trophic diversity (E). Partial eta-squared is the proportion of the variability in the dependent variables that is explained by the effect. The observed power column contains the power values of the F test on the effect. Per every response HAB*LAT interaction was not calculated due to the unbalanced design. Significant values have been marked in bold.

	F	P	Partial eta-squared	Observed power
A) PFI Resident prey				
Intercept	28.89	0.00	0.78	1.00
HAB	0.07	0.80	0.01	0.06
YR	5.86	0.04	0.42	0.57
LAT	0.92	0.37	0.10	0.14
HAB*YR	0.24	0.64	0.03	0.07
YR*LAT	0.04	0.84	0.01	0.05
B) PFI Not-resident prey				
Intercept	33.82	0.00	0.81	1.00
HAB	0.07	0.80	0.01	0.06
YR	5.86	0.04	0.42	0.57
LAT	0.92	0.37	0.10	0.14
HAB*YR	0.24	0.64	0.03	0.07
YR*LAT	0.04	0.84	0.01	0.05
C) PBI Resident prey				
Intercept	70.26	0.00	0.90	1.00
HAB	0.09	0.78	0.01	0.06
YR	5.25	0.05	0.40	0.52
LAT	0.84	0.38	0.10	0.13
HAB*YR	0.37	0.56	0.04	0.08
YR*LAT	0.02	0.89	0.00	0.05

continued

	F	P	Partial eta-squared	Observed power
D) PBI Not-resident prey				
Intercept	21.74	0.00	0.73	0.98
HAB	0.09	0.78	0.01	0.06
YR	5.25	0.05	0.40	0.52
LAT	0.84	0.38	0.10	0.13
HAB*YR	0.37	0.56	0.04	0.08
YR*LAT	0.02	0.89	0.00	0.05
E) Trophic diversity				
Intercept	101.48	0.00	0.93	1.00
HAB	21.07	0.00	0.72	0.98
YR	3.91	0.08	0.33	0.41
LAT	7.42	0.03	0.48	0.67
HAB*YR	1.58	0.24	0.17	0.20
YR*LAT	3.77	0.09	0.32	0.40

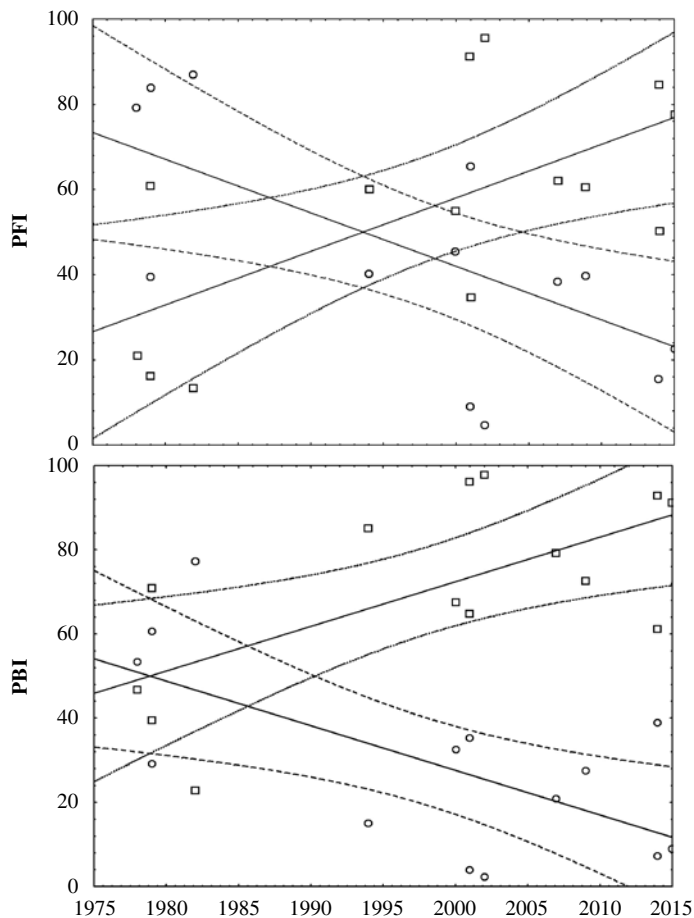


Figure 1. In the Peregrine Falcon diet studied in Italy, year has a positive effect on the numerical (PFI, $r = 0.644$; $P = 0.013$; above) and biomass (PBI, $r = 0.647$; $P = 0.012$; below) percentage of resident species (squares and dotted 95% confidence limits), contrariwise to the negative effect on PFI ($r = -0.644$; $P = 0.013$) and PBI ($r = -0.647$; $P = 0.012$) numerical percentages of not-resident species (circles and dashed 95% confidence limits).

trophic diversity (Simpson index in 1979 = 13.17 vs Simpson index in 2014-15 = 6.06-7.68). It is thus likely that habitat and latitude effects could have confounded the real contribution of time to the reduction of trophic diversity, due to the limited number of available studied sites. Nonetheless, we advise some potential costs on the greatest dependence on Corvidae and Columbidae. For instance some Peregrine Falcon pairs could become more vulnerable to local eradication campaigns of Feral Pigeons or to control programs for Starlings and Jackdaws; as well as they could become more exposed to the risk of contracting *Coccidia*, *Chlamydia* or *Trichomonas* infections from Feral Pigeons (Magnino *et al.* 2009, Schreiber *et al.* 2015). In conclusion our results suggest how a top predator species could potentially adjust its trophic ecology to human-driven ecosystem changes. The Peregrine Falcon confirmed to be an ideal model species for such studies especially if future assessments will provide large scale diet analyses and combine together DNA bar-coding of pellet remains and trail camera recording.

Acknowledgments – We thank Laura Zanca, Beatriz Martinez Miranzo and Rosario Mascara for their support during field work in the Sicilian sites. The Italian Ministry of Education, University and Research (PRIN 2010-2011, 20108 TZKHC) supported this project.

REFERENCES

- AA.VV., 2008. Atlante della biodiversità della Sicilia: Vertebrati terrestri. Collana studi e ricerche ARPA-Sicilia, Palermo.
- Allavena S. & Brunelli M., 2003. Revisione delle conoscenze sulla distribuzione e la consistenza del Pellegrino *Falco peregrinus* in Italia. Atti I° Conv. Ital. Rapaci Diurni e Notturni, Avocetta 27: 20-23.
- Baccetti N., Mongini E. & Spina F., 1984. Contributo allo studio della dieta di *Falco peregrinus brookei* a Montecristo. Rapin-yaires Méditerranis II. Centre de Recerca i Protecció de Rapinyaires, Barcelona: 167-176.
- Bondi S., Prommer M. & Sarà M., 2014. The diet of Saker Falcon *Falco cherrug* overwintering in the Mediterranean (Sicily). Avocetta 38: 53-58.
- Brichetti P. & Fracasso G., 2003-2015. Ornitologia italiana. Vol. 1-9. A. Perdisa Ed., Bologna.
- Buij R., Folkertsma I., Kortekaas K., de Jongh H.H. & Komdeur J., 2013. Effects of land-use change and rainfall in Sudano-Sahelian West Africa on the diet and nestling growth rates of an avian predator. Ibis 155: 89–101.
- Ceccarelli P.P., Gellini S. & Bonora M., 2003. Note sull'alimentazione del Pellegrino *Falco peregrinus* in ambienti urbani dell'Emilia-Romagna. Avocetta 27: 92.
- Chambert T., Kendall W.L., Hines J.H., Nichols J.D., Pedrini P., Waddle J.H., Tavecchia G., Walls S.C. & Tenan S., 2015. Testing hypotheses on distribution shifts and changes in phenology of imperfectly detectable species. Meth. Ecol. Evol. 6: 638-647.
- Cole A. & Serjeantson D., 1996. A manual for the identification of Bird bones from archaeological sites. Archetype Publ., London.
- Dawson R.D., Mossop D.H. & Boukal B., 2011. Prey use and selection in relation to reproduction by Peregrine Falcons breeding along the Yukon River, Canada. J. Rapt. Res. 45: 27-37.
- Donnelly A., Cooney T., Jennings E., Buscardo E. & Jones M., 2009. Response of birds to climatic variability; evidence from the western fringe of Europe. Int. J. Biometeor. 53: 211–220.
- Ferguson-Lee J. & Christie D.A., 2001. Raptors: Birds of prey of the world. A. & C. Black Publ., London.
- Fracasso G., Baccetti N. & Serra L., 2009. La lista CISO-COI degli Uccelli Italiani – Parte prima liste A, B e C. Avocetta 33: 5-24.
- Fraissinet M. & De Rosa D., 2010. Studio della dieta in periodo riproduttivo del Falco Pellegrino *Falco peregrinus* in ambito urbano. Picus 36: 97-103.
- Galimberti A., Spinelli S., Bruno A., Mezzasalma V., De Mattia F., Cortis P. & Labra M., 2016. Evaluating the efficacy of restoration plantings through DNA barcoding of frugivorous bird diets. Conserv. Biol. Doi: 10.1111/COBI.12687.
- García-Salgado G., Rebollo S., Pérez-Camacho L., Martínez-Hestekamp S., Navarro A. & Fernández-Pereira J.M., 2015. Evaluation of Trail-Cameras for Analyzing the Diet of Nesting Raptors Using the Northern Goshawk as a Model. PLoS ONE 10: e0127585. doi:10.1371/journal.pone.0127585.
- Green D.B., Klages N.T.W., Crawford R.J.M., Coetzee J.C., Dyer B.M., Rishworth G.M. & Pistorius P.A., 2015. Dietary change in Cape gannets reflects distributional and demographic shifts in two South African commercial fish stocks. J. Marine Sci. 72: 771–781.
- Gregory R.D., van Strien A., Vorisek P., Mayling A.W.G., Noble D.G., Foppen R.P.B. & Gibbons D.W., 2005. Developing indicators for European birds. Phil. Trans. Royal Soc. B 360: 269-288.
- Leonardi G. & Mannino V., 2007. Feeding habits of urban Peregrine *Falco peregrinus brookei* in eastern Sicily. Avocetta 31: 73-74.
- Magnino S., Haag-Wackernagel D., Geigenfeind I., Helmecke S., Dov A., Prukner-Radovi E., Residbegovi E., Ilieski V., Laroucah K., Donati M., Martinov S. & Kaletac E.F., 2009. Chlamydial infections in feral pigeons in Europe: Review of data and focus on public health implications. Vet. Microbiol. 135: 54–67.
- Massa B., 1981. Le régime alimentaire de quatorze espèces de Rapaces en Sicile. Rapaces Méditerranéens, Ann. du CROP 1: 119-129.
- McCarty J.P., 2001. Ecological Consequences of Recent Climate Change. Conserv. Biol. 15: 320–331.
- Millon A., Nielsen J.T., Bretagnolle V. & Møller A.P., 2009. Predator-prey relationships in a changing environment: the case of the sparrowhawk and its avian prey community in a rural area. J. Animal Ecol. 78: 1086–1095.
- Mocci Demartis A. & Murgia C., 1986. Contributo alla conoscenza dello spettro alimentare del Falco Pellegrino in autunno-inverno. Riv. ital. Orn. 56: 95-105.
- Morganti M., 2015. Birds facing climate change: a qualitative model for the adaptive potential of migratory behavior. Riv. ital. Orn. 85: 3-13.
- Morrison C.A., Robinson R.A., Clark J.A., Risely K. & Gill J.A., 2013. Recent population declines in Afro-Palaearctic migratory birds: the influence of breeding and non-breeding seasons. Div. Distr. 19: 1051–1058.
- Newton I., 1979. Population Ecology of Raptors. T & AD Poyser, Berkhamsted.
- Oro D. & Tella J.L., 1995. A comparison of two methods for studying the diet of the peregrine falcon. J. Rapt. Res. 29: 207-210.
- Pearce-Higgins J.W. & Green R.E., 2014. Birds and Climate Change. Cambridge Univ. Press, Cambridge.
- Pearce-Higgins J.W., Eglinton S.M., Martay B. & Chamberlain D.E., 2015. Drivers of climate change impacts on bird com-

- munities. *J. Animal Ecol.* 84: 943–954.
- Proietti M., Fusacchia P. & Marozza L., 2004. Coppia di Pellegrino (*Falco peregrinus*) in un'area industrializzata del Lazio meridionale: primi dati su biologia ed ecologia. In: Corsetti L. (red.). Atti convegno 'Uccelli rapaci nel Lazio, status e distribuzione, strategie di conservazione'. *Le Scienze* 1: 59-64.
- Rete Rurale Nazionale & LIPU, 2014. Italia – Farmland Bird Index, Woodland Bird Index e Andamenti di popolazione delle specie 2000-2013. www.reterurale.it/farmlandbirdindex/
- Rizzoli F., Sergio F., Marchesi L. & Pedrini P., 2005. Density, productivity, diet and population status of the Peregrine Falcon *Falco peregrinus* in the Italian Alps. *Bird Study* 52:188-192.
- Roulin A., 2015. Spatial variation in the decline of European birds as shown by the barn owl *Tyto alba* diet. *Bird Study* 62: 271-275.
- Robinson, B.G., Franke A., Derocher A.E., 2015. Estimating nestling diet with cameras: quantifying uncertainty from unidentified food items. *Wildl. Biol.* 21: 277–282
- Rutz C., 2012. Predator Fitness Increases with Selectivity for Odd Prey. *Curr. Biol.* 22: 820–824.
- Rutz C., Whittingham M.J. & Newton I., 2006. Age-dependent diet choice in an avian top predator. *Proc. R. Soc. Lond. B* 273: 579–586.
- Sokal R.R. & Rohlf F.J., 1994. *Biometry: The Principles and Practices of Statistics in Biological Research*. W.H. Freeman & Co, New York.
- Schenk H., Chiavetta M., Falcone S., Fasce P., Massa B., Mingozzi T. & Saracino U., 1983. Il Falco pellegrino: indagine in Italia. LIPU, Parma.
- Schreiber T., Kamphausen L. & Haag-Wackernagel D. 2015. Effects of the environment on health of feral pigeons (*Columba livia*). Berlin. München. Tierärztl. Wochenschr. 128: 46-60.
- Serra G., Lucentini M. & Romano S., 2001. Diet and Prey selection of Nonbreeding Peregrine Falcons in an Urban Habitat of Italy. *J. Rapt. Res.* 35:61-64.
- Snow D.W. & Perrins, C.M., 1998. *The birds of the Western Palearctic*, Concise edition. Oxford Univ. Press, Oxford.
- Steenhof, K. & Kochert M.N., 1988. Dietary responses of three raptor species to changing prey densities in a natural environment. *J. Animal Ecol.* 57: 37-48.
- Thiollay J-M., 1982. Les ressources alimentaires, facteur limitant la reproduction d'une population insulaire de faucons pèlerins, *Falco peregrinus brookei*. *Alauda* 50: 1–44.
- Verdari N., 2011. Note sull'alimentazione del Falco Pellegrino svernante nella città di Verona (Veneto, Italia). *Boll. Mus. civ. St. nat. Verona* 35: 15-20.
- Visser M.E., Perdeck A.C., van Balen J.H. & Both C., 2009. Climate change leads to decreasing bird migration distances. *Global Change Biol.* 15: 1859–1865.
- Yanez B., Muñoz A.R. & Ferrer M., 2013. Invertebrates as prey of Short-toed Snake Eagles *Circaetus gallicus*. *J. Rapt. Res.* 47: 320-323.
- Walther G.R., Post E., Convey P., Menzel A., Parmesan C., Beebee T.J., Fromentin J.M., Hoegh-Guldberg O. & Bairlein F., 2002. Ecological responses to recent climate change. *Nature* 416: 389-395.
- White C.M., Cade T.J. & Henderson J.H., 2013. *Peregrine Falcons of the World*. Lynx Ed., Barcelona.

Associate editor: **Michelangelo Morganti**