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Comparison of Pallid Swift *Apus pallidus* diet across 20 years reveals the recent appearance of an invasive insect pest

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Abstract – The diet of the Pallid Swift *Apus pallidus* in a NW Italian breeding colony was examined in the summers of 2012 and 2013 to compare the current diet against those assessed more than 20 years earlier (1987-1990). By screening 5980 prey items found in food boluses brought by adults to nestlings we identified 37 families or superfamilies pertaining to 8 arthropod orders (Araneae, Coleoptera, Diptera, Hymenoptera, Lepidoptera, Mallophaga, Odonata, Hemiptera). The highest percentage of prey was represented by Hemiptera Homoptera (42.9%) and Diptera Brachycera (21.6%), but we also found a good number of Coleoptera (7.0%). We did not find any significant differences in diets after 20 years when comparing prey abundance at higher taxonomic levels, but in the more recent samples, beetles were mostly (above 70%) represented by the allochthonous corn pest *Diabrotica virgifera*, a species totally absent in Italy before the year 2000. We conclude that swift colonies can destroy a huge number of agricultural insect pests, and perhaps even more importantly, regularly checking the swift`s diet at specific localities could be a useful tool for monitoring changes and the biodiversity of flying insects in anthropized ecosystems.

Key-words: *Apus pallidus*, *Diabrotica virgifera*, food, invertebrates, NW Italy.

INTRODUCTION

More than one hundred swift species are specialized aerial-feeder birds (Chantler & Driessens 1995). In particular, the diet of the Common Swift *Apus apus* is well known over time (Weitnauer 1947, Moltoni 1950, Lack & Owen 1955, Tischmacher 1961, Gory 2008), but the Pallid Swift *Apus pallidus* diet also received attention in some Mediterranean countries (Finlayson 1979, Bigot *et al*. 1984), and especially in Italy (Pulcher 1985, Malacarne & Cucco 1992, Cucco *et al*. 1993). In comparison, other species from different biogeographical regions are lesser known (but see: Hespheneide 1975, Collins 1980, Kopij 2000, Collins *et al*. 2010, Garcia-del-Rey *et al*. 2010).

All these studies highlight the general tendency for swifts to feed on a great variety of arthropod species pertaining to the so called "aerial plankton" (Bryant 1973, Waugh 1978), even if a prevalence of some insect taxa (Hymenoptera, Diptera, Hemiptera and Coleoptera) can be detected. The prey species availability, mediated by the selective nature of swift feeding, also favors a large diet variability of the same species in different localities (Cucco *et al*. 1993).

Like many insectivorous bird species, swifts are potentially important elements in the biological control of harmful invertebrates (Kirk *et al*. 1996, Mäntylä *et al*. 2001). Conversely, these birds may be exposed to widespread pesticide use and be sensitive bio-indicators of persistent organic contaminants (Miniero *et al*. 2008). As demonstrated by Nocera *et al*. (2012) a shift in the diet of Chimney Swifts *Chaetura pelagica* over a period of 48 years (1944-1992) was linked to DDT use and its successive ban. Swifts are sensitive to reductions in widespread flying insect populations, as was recently found in Central Europe (Hallmann *et al*. 2017).

We chose to compare the present diet of a Pallid Swift colony in Carmagnola (Turin, NW Italy) to the findings of a study conducted more than 20 years ago in the same site (Malacarne & Cucco 1992, Cucco *et al*. 1993), to investigate any possible variations. During this period, the study area underwent a great urban expansion induced by a 20% human population growth (ISTAT). Agricultural changes, including doubling the extension of cornfields to cover over 51% of the territory (www.sistemapiemonte.it/agricoltura/rete_conoscenze_agri/index.shtml), and local climate trends, including about 1 °C of yearly average temperature increase, were also evident (Boano & Perosino 2014).

METHODS

The Pallid Swift colony in Carmagnola (44.86°N, 7.72°E; elevation 240 m) has been regularly monitored from 1983 onward, including counts, nest surveys, ringing, and biometry (Boano & Cucco 1989, Cucco *et al*. 1992, Boano & Perosino 2014, Boano *et al*. 2015).

For this study, food boluses delivered by adult Pallid Swifts to the nestlings were collected by stimulated regurgitation immediately after feeding and stored in liquid (70% alcohol) in falcon tubes, following the research protocol of Cucco *et al.* (1993).

During 2012, five food-boluses were collected in August and September, and 21 food-boluses were collected in 2013 at 15-day intervals from July to September. The content of food-boluses (964 prey items in 2012 and 5016 in 2013) was analyzed in a petri capsule using a stereomicroscope at the entomological laboratory at the Museum of Natural History of Carmagnola. All the invertebrate specimens were counted, and the insects were identified at least to family level, with few exceptions, following Chinery (1986), Borror *et al*. (1970), and a thorough comparison with the Museum's entomological collection. The head to tail length of each prey item, excluding antennae and caudal appendages, was measured with an ocular micrometer; all values were rounded to the nearest 0.1 mm. The invertebrates were then preserved in liquid (70% alcohol) within cryogenic tubes with external thread reporting collection date and food-bolus origin, and stored in the museum's collections for preservation and for futures analyses.

We compared the diet composition with the results of Malacarne & Cucco (1992) at the lowest taxonomic possible level with Spearman Rank Correlation as suggested by Duffy and Jackson (1986).

RESULTS

We identified 5980 prey items. Arthropod groups and their relative frequency are reported in Table 1. Apart from spiders (Araneae), we identified more than 37 insect families/superfamilies which are included in ten different orders and suborders (see Tab. 1).

The main source of food by number (43% of the total prey number) was represented by Hemiptera Homoptera, found in the food-boluses throughout the research period, and was subdivided among Aphididae, Delphacidae, and to a lesser extent, Cicadellidae and Flatidae, families including polyphagous, phytophagous, and a few vectors of etiologic agents.

Hemiptera Heteroptera were only found in the food-boluses collected in 2013, were relatively abundant (10.5%), and represented many families: Anthocoridae, Geocoridae, Lygaeidae, Miridae, Nabidae, Reduvidae, Saldidae, and Tingidae, that include adephagous and phytophagous taxa, and also Corixidae and Pleidae, typical of aquatic environments.

Coleoptera were found in the food-boluses throughout the research period; we identified Anthicidae, Bruchidae, Carabidae, Coccinellidae, Cryptophagidae, Curculionidae, Latridiidae, Nitidulidae, and Staphylinidae. These taxa include adephagous, saprophagous, and phytophagous elements. In this group, we also found some species typically of aquatic environments from the families Dytiscidae and Helophoridae. The most abundant group was represented by Chrysomelidae beetles, constituted mainly by a large number (215) of western corn rootworm *Diabrotica virgifera* (Le Conte, 1868). This single species made up more than 50% of the total Coleoptera found, and for its relatively conspicuous size (6-7 mm), surely represents a significant portion of consumed biomass.

Diptera Nematocera included only the haematophagous Simuliidae, while the Brachycera belonged to polyphagous, adephagous, and glyciphagous taxa of the families Dolichopodidae, Muscidae, Tephritidae, and Syrphidae, found throughout the research period.

The Hymenoptera Apocrita were represented by arthropophagous, polyphagous, and parasitoid taxa of the superfamilies Chalcidoidea, Cynipoidea, Proctotrupoidea, Vespoidea (all ants), and Ichneumonoidea.

Some prey was very rare, such as Lepidoptera Heterocera and Odonata Zygoptera, and these were found in a few food-boluses collected in 2013, and Hymenoptera Symphyta (superfamily Tenthredinoidea) were only found in a single food-bolus.

Conversely, the Araneae were found in food-boluses during the entire study period; since they are wingless invertebrates, it is presumable that they were preyed upon during ballooning related activities. Lastly, we consider the presence of a single specimen, belonging to the suborder Mallophaga Amblycera found in a food-bolus collected in 2013, presumably due to preening activity.

We cannot highlight a significant difference in prey captured in 1987-1990 (Malacarne & Cucco 1992) com-

Table 1. Arthropods taken by Pallid Swift at the Carmagnola breeding colony (y12 and y13 = number of invertebrates in the food-boluses collected respectively in 2012 and 2013; N = total invertebrate number in the food-boluses; % = percentage frequency).

taxa	y12	y13	N	%
Araneae	**121**	**216**	**337**	**5.64**
Coleoptera			**416**	**6.96**
Anthicidae	1	3		
Bruchidae	-	1		
Carabidae	1	1		
Chrysomelidae	114	187		
Coccinellidae	6	1		
Cryptophagidae	-	1		
Curculionidae	-	14		
Dytiscidae	-	4		
Helophoridae	-	3		
Latridiidae	-	4		
Nitidulidae	1	-		
Staphylinidae	24	50		
Diptera Brachycera			**1293**	**21.62**
unidentified	118	1032		
Dolichopodidae	-	2		
Muscidae	-	60		
Syrphidae	5	53		
Tephritidae	-	23		
Diptera Nematocera			**114**	**1.91**
unidentified	12	88		
Simuliidae	-	14		
Hymenoptera Apocrita			**572**	**9.57**
unidentified	2	7		
Chalcidoidea	-	58		
Cynipoidea	41	-		
Proctotrupoidea	1	-		
Vespoidea	3	457		
Ichneumonoidea	-	3		
Hymenoptera Symphyta			**41**	**0.69**
Tenthredinoidea	-	41		
Lepidoptera Heterocera	-	**7**	**7**	**0.12**
Mallophaga Amblycera	-	**1**	**1**	**0.02**
Odonata	-	**2**	**2**	**0.03**
Hemiptera Heteroptera			**631**	**10.55**
unidentified	35	7		
Anthocoridae	-	49		
Corixidae	-	1		
Geocoridae	-	4		
Lygaeidae	-	260		
Miridae	-	4		
Nabidae	-	47		
Pleidae	-	1		
Reduvidae	-	1		
Saldidae	-	6		
Tingidae	204	12		
Hemiptera Homoptera			**2566**	**42.91**
Aphididae	34	874		
Delphacidae	-	1020		
Flatidae	3	141		
Cicadellidae	238	256		

pared to our samples in 2011-2012 at the lowest possible taxonomic level (Spearman r = 0.90, N = 12, P < 0.01) (Tab. 2). However, looking at this Table, we can see a lower frequency of Hymenoptera in the last sample, balanced by more Diptera and Hemiptera. This difference is probably due to a temporal biased sample, since Hymenoptera in the previous studies were mainly found in June, which is a month when we cannot collect food bolus. The main prey groups also seem similar between different geographic areas (Tab. 3).

The number of prey per bolus is much higher now, averaging 230 (min 4, max 1374, S.D. 217,85) against 140.5, but the mean prey size seems similar, with an average of 3.4 mm (min. 1.4, max 27.0, S.D. 1.8) against an average of 3.9 mm (Cucco *et al.* 1993). However, we observed that the average weight of the adult Pallid Swifts ringed in 1987-1990 was significantly higher than in 2012-13 (40.5 g, S.D. 3.4, n = 182 vs 38.7 g, S.D. 2.94, n = 72; z = 4,20, P < 0.01), suggesting an effect of some sort of stress.

DISCUSSION

Trophic specialization occurs in many communities of aerial feeding birds (Bryant 1978, Waugh 1978, Hespheneide 1975, Cucco *et al.* 1993). In this analysis, we only considered food delivered to nestlings, so we cannot assume that the observed diet corresponds to the usual adult diet as well. Moreover the species, as other Apodidae breeding in Europe, inhabits urban environments, but feeds over a more or less large surrounding area (Gory 2008), mainly across agricultural fields, green urban areas, along rivers, and above woodlands and other remaining natural habitats.

Our observations confirm that Pallid Swift predation of haematophagous insects (Simuliidae) is generally very low. Instead, these birds feed mainly on glyciphagous and phytophagous invertebrates, especially Hemiptera Homoptera (Aphididae, Delphacidae), many families of Heteroptera, and Coleoptera, especially Chrysomelidae. Ar-

Table 2. Comparison of diets between 1987-1990 (Malacarne & Cucco 1992) (A) and 2011-2012 (B) at the lowest possible taxonomic level.

taxa	nA	%	nB	%
Araneae	**173**	1.3	**337**	5.6
Coleoptera	**785**	5.8	**416**	7.0
Diptera	**2262**	16.8	**1349**	22.6
Diptera: Syrphidae	**402**	3.0	**58**	1.0
Hymenoptera	**3186**	23.7	**613**	10.3
Lepidoptera	**4**	0.0	**7**	0.1
Odonata	**2**	0.0	**2**	0.0
Hemiptera: Heteroptera	**634**	4.7	**631**	10.6
Hemiptera: Aphididae	**879**	6.5	**908**	15.2
Hemiptera: Cicadellidae, Delphacidae, Flatidae	**5038**	37.4	**1658**	27.7
Ephemeroptera	**87**	0.6	**0**	0.0
Others	**7**	0.1	**1**	0.0
Total	**13459**	**100**	**5980**	**100**

thropophagous and parasitoid taxa are also represented in the diet by some Hymenoptera.

These findings compare well with other analyses both on Pallid and Common Swifts (Lack & Owen 1955, Cucco *et al*. 1993 and references herein). In particular Homoptera were frequently the highest diet component by number, while Coleoptera, frequently including a large number of Cryshomelidae (e.g. Gory 2008), even if less abundant, may be very important in terms of biomass.

However, it is worth noting the inclusion of an allochthonous crop-pest species, the western corn rootworm (Chrysomelidae*: Diabrotica virgifera*), in the diet. Native to North America, this is the most destructive pest species for maize *Zea mays*, and is a recent invader in Europe. It was first discovered in Serbia in 1992 and in Italy near Venice in 1998, and in the following years showed new disconnected outbreaks in NW Italy (2000) and then in Switzerland, France (2002), Belgium, the United Kingdom, and the Netherlands (2003) (Ciosi *et al*. 2008).

Important natural predators of the western corn rootworm are lacking in Europe (as in the US) (Toepfer & Kuhlmann 2004). For this reason, we think that predation by Pallid Swift on this pest could be important considering that a single swift pair can supply up 20,000 insects in a day to their brood (Lack & Owen 1955), and that swift populations in Europe are still substantial (e.g. more than two hundred breeding birds in our study colony). Obviously this is not “per se” evidence of a regulatory effect of the feeding action of the swift against this or other potentially harmful pest species, but it may be worth considering as a general strategy of integrated pest management (Larramendy & Soloneski 2012)

Table 3. Comparison of Pallid Swift’s prey-abundance (ranks) in different studies based on bolus samples. Hemiptera (Homoptera and Heteroptera) were not splitted in the first two studies.

	Gibraltar	**Morocco**	**Italy** (Turin and Carmagnola)	**Italy** (Carmagnola)
	Finlayson 1979	**Bigot *et al.* 1984**	**Malacarne & Cucco 1992**	**This study**
Taxon				
Homoptera	2	1	1	1
Heteroptera			5	3
Diptera	3	4	3	2
Hymenoptera	1	5	2	4
Coleoptera	4	2	4	5
Araneae	5	3	6	6

On the other hand we must consider that the widespread chemical control of pest species can directly affect swift survival via food poisoning or indirectly via prey reduction. Miniero *et al.* (2008) showed that swifts can act as a bio-indicator of persistent organic micro-contaminants and reported DDE and PCB concentrations two and one order of magnitude lower than those reported as yielding acute effects in other birds suggesting that they may be a good model for future research about potentially sub-lethal effects of contaminants at population levels.

During a period of intense DDT application, Nocera *et al*. (2012) found a reduction in beetles (Coleoptera) and an increase in true bugs (Hemiptera) in the diet of Chimney Swift, probably due to different resistances to DDT within these groups. A similar shift in diet can have energetic consequences, because beetles can provide a greater caloric value than true bugs (Nocera *et al*. 2012). Furthermore, at the same time some studies draw attention to a possible huge reduction in the biomass of insects (Shortall *et al*. 2009, Hallmann *et al*. 2017).

We do not know if this reduction is generalized in terms of insect groups or geographical distribution, and this situation strongly requires more long-term studies or, alternatively, resampling the site after a gap of decades with identical methods (Leather 2018). In this framework, we can easily design a protocol for sampling the diet of swifts at long enduring and easy accessible colonies.

Indeed, by monitoring or resampling the flying invertebrates captured by swifts at specific colonies, we can gather valuable information both about flying insect biodiversity and abundance changes (obviously mediated by the swift's choice), and the influence of these changes on the swift's ecology.

In conclusion, the diet of Pallid Swift chicks in Carmagnola has remained only broadly similar over the past twenty years. However, recent changes in prey composition as a result of the presence of a new pest species and from environmental changes possibly signal an ongoing shift in prey availability. The continued monitoring of chicks' diets is therefore recommended, and we also stress the importance of preserving specimens from the prey samples in museum collections for future comparisons and more in-depth analyses. Swifts can be used to bio-monitor airborne invertebrates in the anthropized environment, similarly to sea birds in marine environment (Furness & Camphuysen 1997).

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