UNIVERSIDADE DE ÉVORA

ESCOLA DE CIÊNCIAS E TECNOLOGIA

DEPARTAMENTO DE BIOLOGIA

BARN SWALLOWS' DIET IN THE MONTADO |

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Orientação: Doutor Jaime Ramos |
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Mestrado em Biologia da Conservação

Dissertação

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Dieta de andorinha-das-chaminés em áreas de montado

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Resumo

As aves são um grupo importante no equilíbrio dos ecossistemas devido aos serviços que proporcionam. A andorinha-das-chaminés é uma ave insectívora geralmente associada a actividades humanas, com a sua dieta baseada em estádios voadores de insectos, principalmente Diptera, Hymenoptera e Coleoptera. Neste estudo, avaliámos a dieta de uma população de andorinha-das-chaminés nidificante num ecossistema seminatural – o montado –, aplicando o método do colar em crias. Avaliámos se existiam diferenças na composição da dieta entre períodos de amostragem ao longo de Abril e Maio de 2012, bem como entre dípteros de diferentes funções ecológicas. Os resultados confirmaram a preferência pelas três ordens insectívoras descritas, com Diptera totalizando 65%. Não foram registadas diferenças na biomassa média consumida entre períodos, idade das crias e funções ecológicas, mostrando um equilíbrio no consumo energético, embora haja consumo de diferentes tipos de presas.

Palavras-chave: *Hirundo rustica*; ecossistema seminatural; cria; insectívoro; Diptera.

Barn swallow's diet in the *montado*

Abstract

Birds are an important group in the equilibrium of the ecosystems due to the services they provide. The barn swallow is an insectivorous bird generally associated to human activities, with their diet being based on winged life stages of insects, mainly Diptera, Hymenoptera and Coleoptera. We evaluated the diet of a barn swallow population breeding in a semi-natural ecosystem – the *montado* –, applying the ligature method on nestlings. We evaluated if there were differences in the diet among sampling periods along the months of April and May (2012), as well as among different ecological functions of Diptera. Results confirmed the preference for the three main insect orders, with Diptera reaching 65% of the total. There were no differences in mean biomass consumed throughout periods, nestling's age and ecological functions, showing equilibrium of the energetic intake despite the different types of prey consumed.

Keywords: *Hirundo rustica*; semi-natural ecosystem; nestling; insectivore; Diptera.

Introduction

Birds are an important group for the maintenance of the ecosystem's equilibrium since they provide a wide range of ecosystem services, mainly due to their different ecological and physical characteristics; one of these important characteristics is birds' high mobility, which enables them to link different habitats and ecosystems through their natural movements and migrations. Ecosystem services provided by birds can be divided in product-driven and behaviour-driven (Whelan *et al.* 2008). The first is related to the provisioning and supporting of systems, by acting in nutrient dynamics, feeding opportunities of different species and/or the construction of nests. Behaviour-driven services are related with foraging behaviour, which includes pollination, seed dispersal, symbiosis with other species, scavenging and pest control (e.g., insects, rodents, weeds). Insectivorous birds have an especially important role in controlling populations of insects in the ecosystems and maintaining the natural equilibrium. Studies have shown that heterogeneous forests and agroforestry systems suffer less damage on their flora by herbivorous arthropods, as consequence of the high abundance of birds acting as regulators of arthropod populations (Van Bael *et al.* 2008; Whelan *et al.* 2008; Bereczki *et al.* 2014).

Barn swallows (*Hirundo rustica*) are insectivorous birds specialized in catching their prey during flight – aerial sweepers. Their diet is composed mostly by flight insects, although other arthropods (e.g. arachnids) can be consumed. This migratory species has a wide distribution throughout the globe, breeding in the Palearctic and North America, and wintering in the southern hemisphere (Cramp *et al.* 1988). In continental Portugal, it is distributed all over the country with higher abundances in the south and coastal areas (Equipa Atlas 2008).

This species has a generalist diet, consuming several types of invertebrates, essentially beetles and weevils (Coleoptera), ants, bees and wasps (Hymenoptera), and flies (Diptera) (Cramp *et al.* 1988; Catry *et al.* 2010; Turner 2010; Capinera 2011). This diet varies according to habitat and season, depending on the species of insects available. During the breeding season, barn swallows tend to use smaller hunting areas, closer to the nests (Møller 2001; Orłowski and Karg 2011), and adults tend to feed nestlings with different species of insects than when self-feeding – adults' diet is based on Coleoptera, Hymenoptera and Diptera, whilst chicks' diet is based essentially on

Diptera (Turner 1982, 2010). In addition to food, barn swallows also ingest and provide grit to their young, as a probable source of calcium and to help in the digestion of the exoskeleton of insects (Barrentine 1980; Turner 2010).

Barn swallows breed individually or in small colonies, building their nests of mud and different kinds of fibres in natural or artificial structures. Their breeding season usually goes from May to August; in Portugal, however, this period is enlarged according to their location – in the south and centre, clutches are found as early as February, whereas birds in northern Portugal raise their nestlings until July (Catry *et al.* 2010). They lay two to three clutches per year, with four to five eggs each, having an incubation period of 15 days. The parents feed the nestlings by collecting prey during foraging bouts in a bolus, sometimes helped by the older fledglings, from the first clutch. Nestlings fledge around 19 days old (Cramp *et al.* 1988; Catry *et al.* 2010).

Often found associated to human activities, this species plays an important ecological role across several environments, from rural to urban areas. The predator-prey interaction with flying insects suggests that barn swallow populations may be used to control insect populations – as an indirect way of monitoring insects' decline (Hallmann *et al.* 2017; Vogel 2017), or aiding humans in the control of pest booms in a specific region. However, in regards to pest control, it is difficult to ascertain the impact of the insectivore on the pest population's decline, as it needs to have a clearly negative impact on its population (Whelan *et al.* 2008).

Several authors have studied barn swallows' diet across European and North American countries, from urban to rural areas (Kopij 2000; Møller 2001; Orłowski and Karg 2011, 2013; Law *et al.* 2017). However, there are few studies in semi-natural areas, and therefore their potential role as pest controllers has not been addressed in areas such as the Mediterranean oak woodlands, an agroforestry system typical of southern Portugal.

Mediterranean oak woodlands are mainly found in the Iberian Peninsula (commonly designated by *montado* in Portugal and *dehesa* in Spain), where oak populations are frequently managed by humans in at least one of the following production activities – forestry, agriculture and livestock, hunting or tourism (Pereira *et al.* 2015). This complex semi-natural ecosystem originated when humans started using forests of cork oak (*Quercus suber*) and holm oak (*Q. rotundifolia*) for cattle grazing, where the animals also fed on the acorns (Pereira *et al.* 2015). Throughout the centuries, the forests were modified towards what today is a savannah-like mosaic of floral and faunal species with a high biodiversity (Pinto-Correia *et al.* 2011; Pereira *et al.* 2015). This is achieved due to a multi-functionality inherent of the *montado,* by allying the diversity of plants – with presence of other oaks (*Q. robur*, *Q. faginea* and *Q. pyrenaica*), pine trees (*Pinus pinea* and *P. pinaster*), sometimes common olive tree (*Olea europaea*), and several typical shrub formations like *Q. coccifera*, *Cistus* spp., *Pistacia lentiscus*, *Phillyrea angustifolia*, and others – with the human activity, creating multiple refuges and feeding places for the local fauna.

However, when the *montado* is threatened, because it is a human-influenced ecosystem, it does not have the ability to naturally regenerate effectively. Over-exploitation of tree cover, intensification of activities on the undercover, and pest infestations are the main threats to the *montado*, weakening the trees and not guaranteeing their long-term recovery. Fortunately, the importance of the conservation of the *montado* is nowadays acknowledged internationally, not only by its economic value, with the production of cork, but also because of its natural values, such as the upkeep of biodiversity, the aesthetic of its landscape, and the environmental balance it provides (Pinto-Correia *et al.* 2011).

In this study, we evaluate the diet of a barn swallow population breeding in a *montado* area. This assessment is based on nestling diet throughout the breeding season. The evaluation consists of a qualitative and quantitative categorization of the diet, comparing between 10 day-period of the nestling season, nestlings' age, types of prey, and biomass.

Given that most other studies were in urban and rural areas, our study seems to be the first to address the diet of this species specifically in a semi-natural forest ecosystem. Therefore, it will provide better insight as to whether the barn swallow will prey on different species and groups of insects with different ecological functions. It will as well provide new conservation possibilities for the *montado* based on the interactions between the swallows and the ecosystem.

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Research Paper

Barn swallow's diet in the *montado*

Cláudia Lopes; Carlos Godinho; Ricardo Ceia; Jaime Ramos

Abstract

Birds are an important group in the equilibrium of the ecosystems due to the services they provide. The barn swallow is an insectivorous bird generally associated to human activities, with their diet being based on winged life stages of insects, mainly Diptera, Hymenoptera and Coleoptera. We evaluated the diet of a barn swallow population breeding in a semi-natural ecosystem – the *montado* –, applying the ligature method on nestlings. We evaluated if there were differences in the diet among sampling periods along the months of April and May (2012), as well as among different ecological functions of Diptera. Results confirmed the preference for the three main insect orders, with Diptera reaching 65% of the total. There were no differences in mean biomass consumed throughout periods, nestling's age and ecological functions, showing equilibrium of the energetic intake despite the different types of prey consumed.

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Introduction

Birds are an important part of the ecosystems due to their ecological functions and the services they provide, such as pollination, seed dispersal and pest control (Whelan *et al*. 2008). Insectivorous birds have an especially important role in controlling populations of insects in the ecosystems and maintaining the natural equilibrium. Studies have shown that heterogeneous forests and agroforestry systems suffer less damage on their flora by herbivorous arthropods, as consequence of the high abundance of birds (Van Bael *et al*. 2008; Whelan *et al*. 2008; Bereczki *et al*. 2014).

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Barn swallows breed individually or in small colonies, building their nests of mud and different kinds of fibres in natural or artificial structures. The breeding season usually goes from May to August (Catry *et al*. 2010). They lay two to three clutches a year, with four to five eggs each. The parents feed the nestlings by collecting prey during foraging bouts in a bolus, sometimes helped by the older fledglings (from the previous clutch). Nestlings fledge around 19 days old (Cramp *et al*. 1988; Catry *et al*. 2010).

Often found associated to human activities, this species plays an important ecological role across several environments, from rural to urban areas. The predator-prey interaction with flying insects suggests that barn swallow populations may be used to control insect populations – as an indirect way of monitoring insects' decline (Hallmann *et al*. 2017; Vogel 2017), or aiding humans in the control of pest booms in a specific region. However, in regards to pest control, it is difficult to determine the impact of the insectivore on the pest population's decline, as it needs to have a clearly negative impact on its population (Whelan *et al*. 2008).

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Mediterranean oak woodlands are mainly found in the Iberian Peninsula (commonly designated by *montado* in Portugal and *dehesa* in Spain), where oak populations are frequently managed by humans in at least one of the following production activities – forestry, agriculture and livestock, hunting or tourism (Pereira *et al*. 2015). This complex semi-natural ecosystem originated when humans started using forests of cork oak (*Quercus suber*) and holm oak (*Q. rotundifolia*) for cattle grazing, where the animals also fed on the tree's acorns. (Pereira *et al*. 2015). Throughout the centuries, the forests were modified towards what today is a savannah-like mosaic of floral and faunal species with high biodiversity (Pinto-Correia *et al*. 2011; Pereira *et al*. 2015).

However, when the *montado* is threatened, because it is a human-influenced ecosystem, it does not have the ability to naturally regenerate effectively. Over-exploitation of tree cover, pest infestations and intensification of activities on the undercover are the main threats to the *montado*, weakening the trees and not guaranteeing their long-term recovery. Fortunately, the importance of the conservation of the *montado* is nowadays acknowledged internationally, not only by its economic value, with the production of cork, but also because of its natural values, such as the upkeep of biodiversity, the aesthetic of its landscape, and the environmental balance it provides (Pinto-Correia *et al*. 2011).

In this study, we evaluate the diet of a barn swallow population breeding in a *montado* area, based on nestling diet throughout the breeding season. The evaluation consists of a characterization and quantification of the arthropods consumed by barn swallow; we also test changes in diet composition and biomass through the breeding season. Given that most other studies were in urban and rural areas, our study seems to be the first to address the diet of this species in a montado system. Therefore, it will provide better insight as to whether the barn swallow will prey on different species and different functional groups of insects. It will as well provide new conservation possibilities for the *montado* based on the interactions between the swallows and the ecosystem.

Methods

Study area

The study was carried out in the Herdade do Freixo do Meio (38º42’10’’N, 8º19’31’’W), a farm located in Montemor-o-Novo council, southwestern Portugal. This region is characterized by dry, hot summers and humid, temperate winters, typical of a Mediterranean climate – average temperature ranges from *8.0 ºC* in January to *25.2 ºC* in August, with an annual mean temperature of *15.6 ºC*, and annual mean precipitation of *398.2 mm* (IPMA 2015, 2018).

The study area is characterized by a sparse *montado* sometimes mixed with stone pine (*Pinus pinea*) or olive (*Olea europaea*). The management of these woodlands is done essentially by combining the extensive rearing of sheep and Iberian pigs (shrub cutting, fodder and grain production) with the harvest of cork from mature cork oak trees (approximately every nine years), as well as by the occasional pruning and cutting of decaying and/or dead trees for fuelwood. Shrub understories are a typical combination of grasslands with shrub formations of *Cistus* spp., *Asparagus acutifolius, Ulex australis* subsp. *welwitschianus, Pistacia lentiscus, Arbutus unedo, Phillyrea angustifolia, Crataegus monogyna, Quercus coccifera* and *Lavandula pedunculata*, ranging from low to high densities.

Diet sampling

We studied nests located in isolated buildings, at least 500 m apart from the nearest human infrastructure. Nests with eggs were monitored in order to know the exact hatching date, which was used to calculate nestling’s age. Barn swallow’s diet was assessed with the ligature method since it allows a detailed identification of samples (Johnson *et al*. 1980; Turner 1980). The ligature method consisted in positioning a cotton coated wire around the neck of the nestlings (aged 8-18 days). This technique allows normal breathing while preventing swallowing, enabling the subsequent collection of the food items. To minimize any negative impact on nestlings, ligatures were not kept for more than two hours at a time ($\bar{X}$ = 1h04 ± 00h13, mean and SD) and nestlings were fed with captured flies after sample collection (Waugh 1978; Turner 1980). Nests were checked for invertebrates before application of the ligatures to ensure all items found in the nest after sampling were regurgitated prey and therefore included in the analyses. Samples were preserved in 70% ethanol, with the indication of nest and nestling's ring number.

The sampling period ran from April to May of 2012, with available nests being visited once a day, between 8:00h and 20:00h. As this resulted in a large number of samples, we conducted a sub-sampling by randomly selecting three boluses per day, whenever possible from different nestlings and nests to maximize variability. The subsequent sub-sample of 32 days was then divided into three periods: 19-30 April (1), 1-19 May (2) and 20-31 May (3).

Arthropod Identification

In a first phase, samples were screened with a binocular microscope of 60x magnification, separating the different items (arthropods) of each bolus. These were numbered and identified to order. Arthropod's length (to the nearest 0.1 mm) was measured from head to abdomen, excluding all appendixes, by placing the item over millimetre paper. Arthropods were then organized in size classes according to length: class 1 (0.1-4.0 mm), class 2 (4.1-8.0 mm), class 3 (8.1-12.0 mm), class 4 (12.1-16.0 mm) and class 5 (16.1-20.0 mm).

Items' biomass was calculated using the equation and coefficients (Table 1) proposed by Sample *et al.* (1993), due to the climate similarities between the study areas, and the accuracy of Sample's equations, tested in Spanish south-eastern arthropods (Hódar 1996). The general equation (Insecta) was used for insect orders without specific formulas, while Arachnida's biomass was neglected, as very few Arachnida were found, i.e. around 1%.

In a second phase, Diptera were identified to the family according to Hjorth-Andersen (2004) and Oosterbroek (2006), using a binocular microscope with a magnification of 80x. Each family was connected to an ecological function (Table 2) based on the general physical and ecological characteristics of the adults (Powell and Hogue 1980; Oosterbroek and Hurkmans 2006): (1) *Predator* – families where most or all of the genera are active predators on other invertebrates; (2) *Parasitoid* – their life cycle is dependent on the death of a host; (3) *Multi-functional* – genera too diverse to attribute to only one functionality; (4) *Saprophagous* – consumption of decayed matter; (5) *Nectarivore/Palynivore* – feeding almost exclusively of nectar and pollen; (6)

Unknown/Neutral – without any specific ecological function and those whose insects don't actively participate in any of the other functions.

Table 1. Coefficients used to calculate insects biomass; Sample's equation is $\boldsymbol{B} = \boldsymbol{e^b} \times \boldsymbol{L^a}$, where *B* is Biomass, *L* is Length, *a* and *b* are the coefficients

Taxon	Coefficient	
	a	*b*
Insecta	2.494	-3.628
Coleoptera	2.492	-3.247
Diptera	2.213	-3.184
Hemiptera	3.075	-4.784
Homoptera	2.225	-2.823
Hymenoptera	2.696	-4.284
Lepidoptera	3.122	-5.036
Neuroptera	2.57	-4.483
Trichoptera	3.044	-4.61

Data Analyses

Chi-squared tests were used to evaluate if: (1) the number of items collected per order, and (2) the defined ecological functions of Diptera, were equally distributed among periods. As there were several orders with numbers too low for the first test to be accurate, orders with a number of items below five (Arachnida, Lepidoptera, Psocoptera, Neuroptera, Raphidioptera, Trichoptera and Not Identified) were aggregated in one group named "Others", which was tested with Coleoptera, Diptera, Hemiptera, Hymenoptera and Isoptera.

Data on insects' biomass was log10 or square root transformed, prior to the Shapiro-Wilk test to access normality. Linear Mixed Models (LMM) were then used to determine differences in mean biomass, using the period and nestling's age as explanatory variables, and bolus|nest as a random factor. The models produced were compared with the null model using AIC. Tests were replicated for the most representative orders and families.

All statistical analyses were done using software program R3.4.2, associated with RStudio (RStudio Team 2016; R Development Core Team 2017).

Results

General results

In total, 158 diet samples (= boluses) from 32 nestlings were collected from seven different nests, plus 50 boluses found inside the nests. Diet analyses were carried out using a subsample of 86 boluses and 1065 items, belonging to 11 identified orders (Fig. 1).

Diptera was the most representative order, with 691 items (65%), followed by Hemiptera (14%) and Isoptera (10%) (Fig. 1).

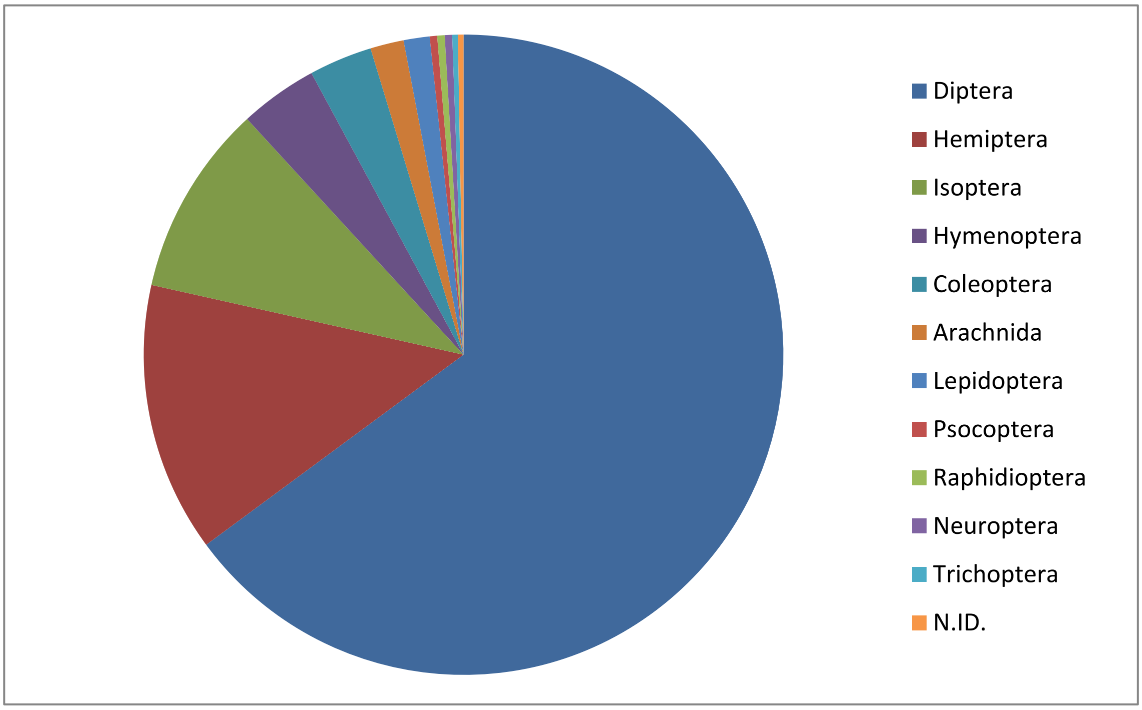

Fig. 1. Percentage of each prey in the diet of barn swallow at Freixo do Meio, Montemor-o-Novo, in April-May 2012 (n = 1065).

Of the 44 identified Diptera families (Table 2), Chironomidae was the one with a higher percentage, with a total of 169 items (24.5%), followed by Empididae with 101 items (14.6%); however, most of the families' percentage on diet was below 3.0% (Table 2).

Table 2. Diptera families present in barn swallow diet at Freixo do Meio, including their ecological category, number of items by period – 19-30 April (1), 1-19 May (2), and 20-31 May (3) – and in total, total percentage and total biomass.

Family	Ecological function	1st Period	2nd Period	3rd Period	Total items	%	Total Biomass (mg)
Chironomidae	Unknown/Neutral	165	2	2	169	24.5	530.1
Empididae	Multi-functional	36	38	27	101	14.6	228.5
Tabanidae	Multi-functional	-	20	28	48	7.0	259.3
Anthomyiidae	Multi-functional	32	5	9	46	6.7	71.0
Bombyliidae	Nectarivore/Palynivore	-	3	40	43	6.2	127.2
Muscidae	Multi-functional	14	8	12	34	4.9	124.9
Syrphidae	Nectarivore/Palynivore	3	11	10	24	3.5	129.6
Tachinidae	Nectarivore/Palynivore	9	7	5	21	3.0	78.5
Tipulidae	Unknown/Neutral	15	1	4	20	2.9	230.8
Simuliidae	Multi-functional	15	2	-	17	2.5	9.5
Acroceridae	Nectarivore/Palynivore	-	14	2	16	2.3	32.7
Dolichopodidae	Predator	1	3	11	15	2.2	24.3
Sciaridae	Unknown/Neutral	11	2	1	14	2.0	9.9
Calliphoridae	Multi-functional	4	8	1	13	1.9	59.5
Scathophagidae	Multi-functional	4	-	6	10	1.5	23.2
Mycetophilidae	Multi-functional	7	1	1	9	1.3	7.5
Psilidae	Unknown/Neutral	4	-	5	9	1.3	6.2
Asilidae	Predator	-	8	-	8	1.2	15.7
Sphaeroceridae	Saprophagous	7	1	-	8	1.2	3.5
Stratiomyidae	Nectarivore/Palynivore	1	5	1	7	1.0	30.8
Therevidae	Multi-functional	-	-	7	7	1.0	41.8
Heleomyzidae	Unknown/Neutral	1	-	3	4	0.6	4.8
Pipunculidae	Parasitoid	2	1	1	4	0.6	3.9
Ceratopogonidae	Multi-functional	3	-	-	3	0.4	1.7
Lonchaeidae	Saprophagous	1	2	-	3	0.4	3.7
Sepsidae	Unknown/Neutral	-	-	3	3	0.4	2.7
Tephritidae	Multi-functional	1	1	1	3	0.4	2.5
Bibionidae	Unknown/Neutral	1	-	1	2	0.3	2.4
Conopidae	Multi-functional	-	2	-	2	0.3	9.0
Dixidae	Unknown/Neutral	2	-	-	2	0.3	1.0
Fannidae	Unknown/Neutral	-	-	2	2	0.3	4.0
Phoridae	Multi-functional	1	1	-	2	0.3	0.4
Platypezidae	Multi-functional	2	-	-	2	0.3	1.1
Psychodidae	Unknown/Neutral	2	-	-	2	0.3	0.5
Sarcophagidae	Nectarivore/Palynivore	-	2	-	2	0.3	6.5
Scatopsidae	Nectarivore/Palynivore	1	1	-	2	0.3	1.3
Chaoboridae	Unknown/Neutral	1	-	-	1	0.1	2.2
Cnemospathidae	Unknown/Neutral	1	-	-	1	0.1	0.3
Drosophilidae	Saprophagous	1	-	-	1	0.1	0.2
Dryomyzidae	Saprophagous	1	-	-	1	0.1	3.1
Keroplatyiidae	Multi-functional	1	-	-	1	0.1	1.2
Lauxaniidae	Unknown/Neutral	-	-	1	1	0.1	0.9
Milichidae	Multi-functional	-	1	-	1	0.1	0.5
Rhagionidae	Multi-functional	1	-	-	1	0.1	4.1
N.ID.	Unknown/Neutral	3	-	3	6	0.9	0.9
TOTAL		**354**	**150**	**187**	**691**	**100**	**2103.3**

Size and Number of Prey during growth

Throughout the nestling growth period (from 8 to 18 days old), barn swallows were fed, in a higher quantity, prey of smaller size classes, rather than arthropods of higher size classes (Fig. 2).

When the nestlings had between 8 and 10 days old, they were mainly fed size class 2 arthropods, combined with classes 1 and 3 in lower numbers. As they grew older, there was an increase in the number of prey consumed, sporadically with bigger arthropods (classes 4 and 5). As the nestlings approach the age of 18 days old, the number of items decreased.

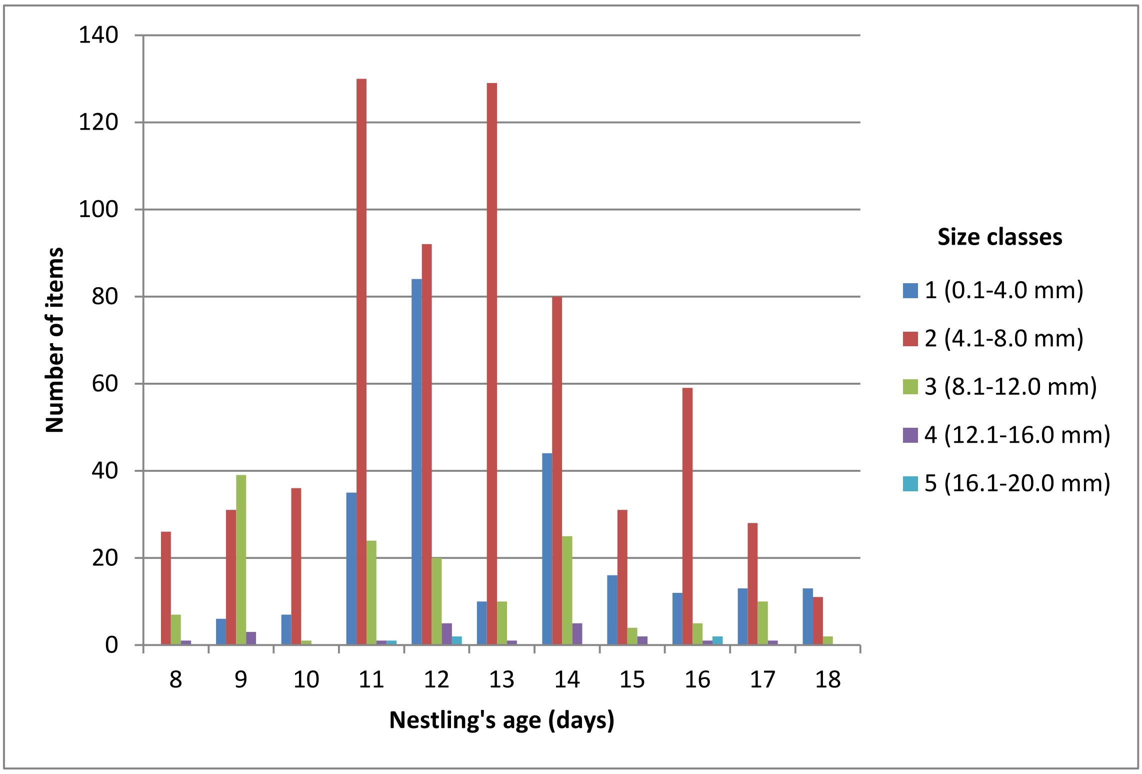

Fig. 2. Number of arthropod items and size classes consumed by barn swallow nestlings throughout their growth (days old).

Despite the differences found in the size of the prey, the average biomass per item consumed was constant along the nestling development (Fig. 3).

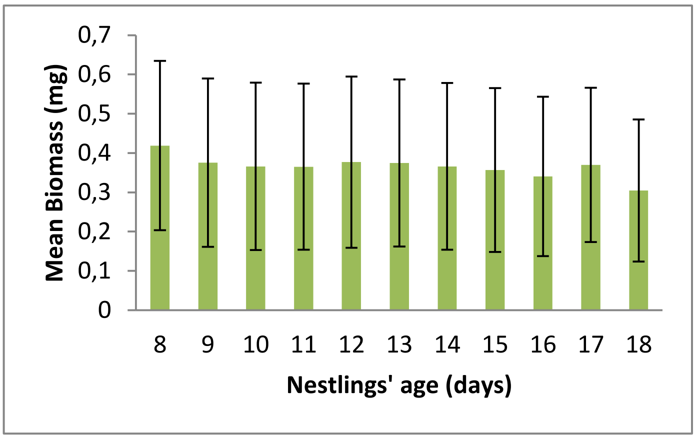

Fig. 3. Mean ± standard deviation biomass per item consumed according to nestling's age (days old).

Diet throughout the breeding season

The chi-squared test showed that arthropod items per order were not equally distributed among the three periods (P < 0.001). Similar result was obtained for the ecological functions of the insects, with a P < 0.001 (Annexes – Fig. 8).

The LMM test was applied to check for differences in bolus' mean biomass between periods, nestling age and a combination of these factors. No differences were found, as the comparison between models showed the null model as the best, with the other models having a delta AIC over 4 (Fig. 4 and 5).

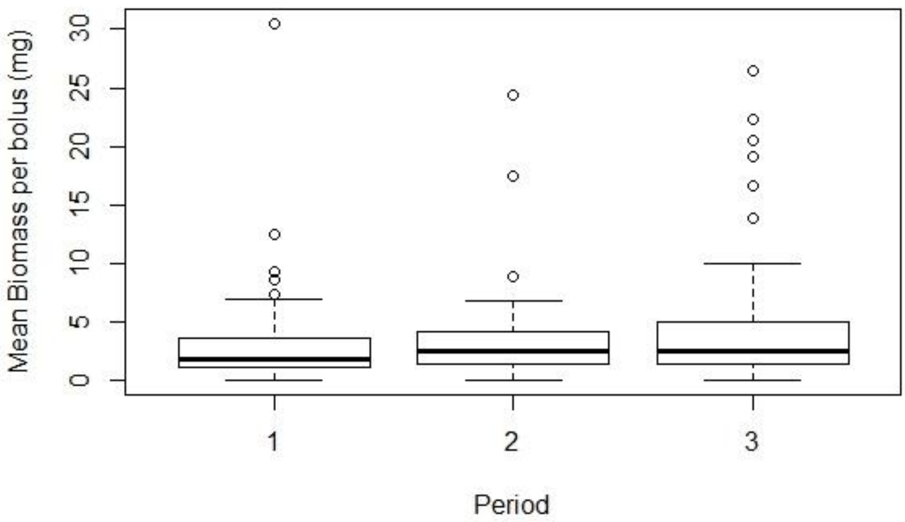

Fig. 4. Mean biomass per bolus consumed by barn swallow nestlings in each period: 19-30 April (1), 1-19 of May (2) and 20-31 of May (3).

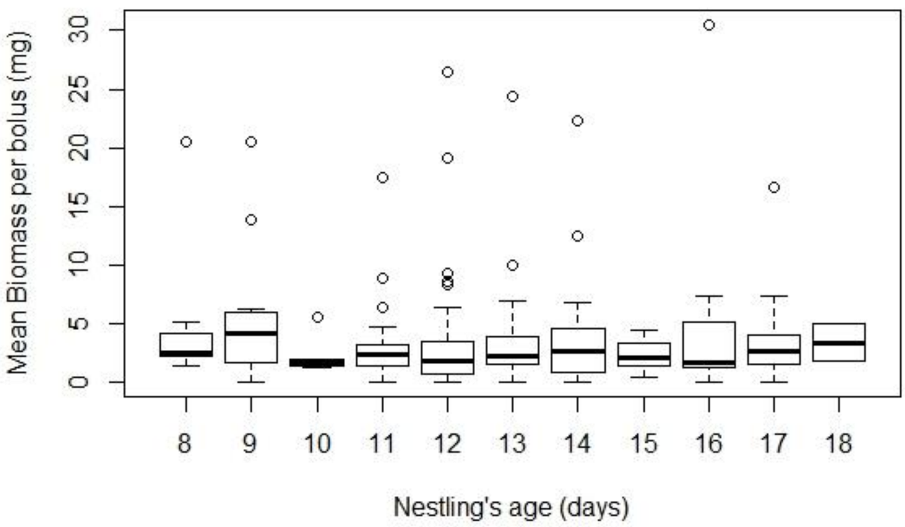

Fig. 5. Mean biomass per bolus consumed by barn swallow nestlings during growth (days old).

Differences were tested for the most representative orders (Fig. 6, and Fig. 9-12 of annexes) and families (Fig. 7, and Fig. 13-18 of annexes), using the same variables. The null model, in the LMM tests, was always the best model (models presenting delta AIC over 4), indicating that there were no differences. Some orders and families were not able to be tested due to the non-normal distribution even after transformation, as is the case with the order Hymenoptera and the family Empididae (Fig. 11 and 13, respectively, of annexes).

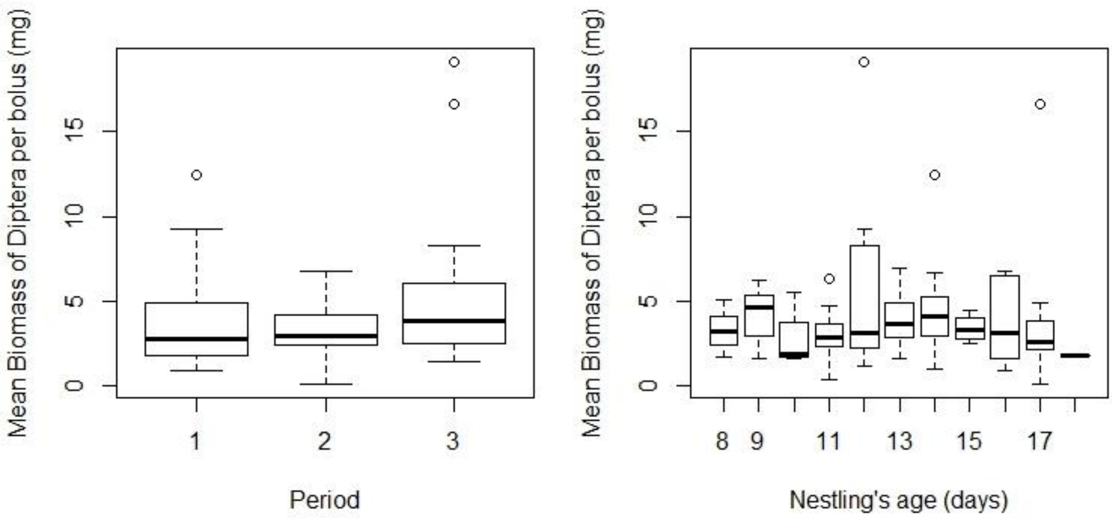

Fig. 6. Mean biomass per bolus of the order Diptera in each period – 19-30 April (1), 1-19 May (2), and 20-31 May (3) – and according to nestlings' age (days old).

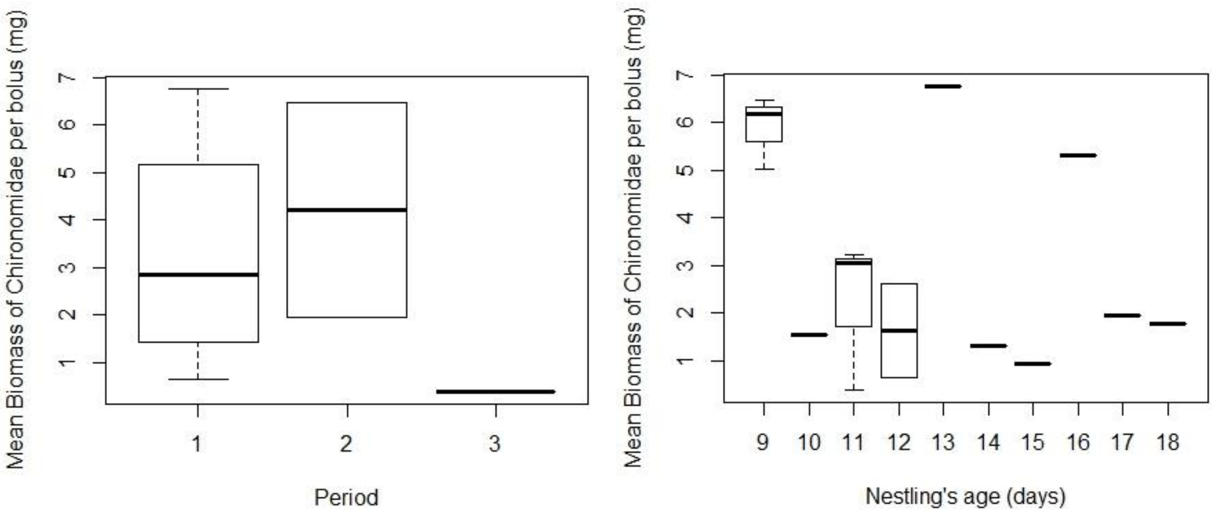

Fig. 7. Mean biomass per bolus of the family Chironomidae in each period – 19-30 April (1), 1-19 May (2), and 20-31 May (3) – and according to nestlings' age (days old).

Discussion

Our study showed that barn swallow nestlings' diet in the *montado* is composed mainly by Diptera and Hemiptera, with a constant mean biomass intake throughout the nestling season of April and May. We also highlighted the diversity of other arthropods consumed by the hirundine in this system, revealing the richness of this habitat.

There are different studies published about barn swallow's diet. However, most of them are performed in rural areas, with a few being in urban areas. These studies are diverse in methodology for collecting the prey, which turns comparisons between them difficult, as the results vary according to the methods used. Independently of the study area being rural or urban, studies with stomach content show similar diet results – the most abundant orders consumed were Coleoptera, followed by Hymenoptera, with Diptera having much lower frequencies (Kopij 2000; Orłowski and Karg 2011; Law *et al*. 2017). These results contrast with those we obtained, where Diptera was the most abundant order in the diet. The difference might be related with the method of prey collection and the age of the barn swallow's individuals used for the studies: stomach content has already been partially or completely digested, with arthropods with less chitin being harder to identify; barn swallow's corpses used for studying the stomach content were all of adult individuals, while the ligature method is usually applied to nestlings. Our results show that in the early stages of nestlings' development, Diptera is the most consumed order (65%), which is in agreement with what is observed in other ecosystems (Turner 1982, 2010). This is further supported by a work in Denmark, where Møller (2001) evaluated the barn swallow nestlings' diet using the ligature method, obtaining results similar to ours – a strong abundance of Diptera in the diet, followed by the other orders, with much lower frequencies.

As Diptera was the most significant order in our study, we decided to further study it. To do so, we identified its items to the family, revealing a surprising amount of different families - 44 identified in total. Of these, Chironomidae was the most abundant, although making up only 24.5% of the total. The ecological functions of these families were difficult to categorize, as each have different functions and interactions with the ecosystems they inhabit, sometimes differing with each genera. These results heavily suggest that the barn swallow is generalist in its feeding, even in a semi-natural forested habitat.

The data analyses showed that the nestling's food intake along their development seems to be essentially composed by smaller arthropods, between 0 and 8 mm. Despite the size class and biomass sum appearing to fluctuate according to the age of the nestlings, the mean biomass was stabled around 0.38 ± 0.21 mg. The tests, further supported by the LMM results, imply that despite the apparent selection of different orders, and even different ecological functions of prey, the energy intake is constant, with no significant changes during nestlings' growth.

This generalist diet of the barn swallow, with different orders and families being preyed on throughout the nestling period, may suggest a valuable role of this species in controlling booms of pest insects within the preferred size classes consumed. The large consumption of Isoptera in our study occurs only in a few strict days, in the end of April; this may imply the existence of an Isoptera boom during that time period, to which the barn swallow took advantage and preyed on. These suggestions are supported by Beal (1918, cited in Turner 2010) who verified large quantities of the same insect prey in a barn swallow stomach, when the insect was available. Ceia and Ramos (2016) review the role of birds in the control of pests in the *montado*, and noticed that having a fairly generalist diet is important in pest control, as birds will feed on the most abundant prey, and therefore on pest outbreaks.

As our study is focused on a population of barn swallow breeding in the *montado*, the results it brings may be applied to the categorization and conservation of this semi-natural forested habitat. On one side, by studying their diet, we indirectly analysed the different kinds of arthropod species existent in the area, consequently helping to categorize the biodiversity of the system, an important factor for its conservation. On another side, one of the greatest threats to the *montado* are its pests, usually very specific species of Coleoptera and Lepidoptera (Pereira *et al*. 2015; Ceia and Ramos 2016). With our study we show that these orders appear in very low numbers on the barn swallows' diet. Although this means it is probably inviable to use this passerine as a direct way to control these *montado* pests, they are still a valuable resource in the system by maintaining the equilibrium of all the other species they consume and, subsequently, the *montado* itself. We cannot completely discard, either, the possibility of the importance that these hirundine populations have on insect booms, by preying on the most abundant, and consequently reducing their numbers and the possible consequences these could have, even if they are not a direct threat to the ecosystem.

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Discussion

There are different studies published about barn swallow diet. However, most of them were performed in rural areas, with a few in urban areas. These studies have different methodologies for collecting the prey, which turns comparisons between them difficult, as the results vary accordingly to the methods used.

In Poland, a study conducted by Orłowski and Karg (2011) showed that barn swallow's diet was dominated by Coleoptera (56%), followed by Hymenoptera (24%). In another location in rural Poland (Orłowski and Karg 2013), they also showed that there were slight differences in the bird's diet if the farms had livestock (more quantity of Coleoptera and Hymenoptera). In these studies, these two orders have a higher impact on barn swallow's diet than Diptera (around 12%).

Law *et al.* (2017) published a study on barn swallow's diet using adult swallows' carcasses (due to plane activity) near the airport of Vancouver, Canada. In this urbanized area, the majority of the insects eaten by the barn swallows were Hymenoptera (40%), followed by Diptera (31%).

A study on swifts and swallows from South Africa noted that barn swallow's diet was composed by 56.9% of Coleoptera, 12.5% of Hymenoptera, 7.6% of Isoptera, 3.4% of Diptera, 2.4% of Heteroptera and 0.5% of other orders (Kopij 2000).

All of these studies show low frequencies of Diptera in the barn swallow's diet; these results may be influenced by the sampling methodology since they are based on stomach contents and faecal sacs. Additionally, all individuals studied were adults which may also have an influence on the results, as it has been demonstrated that their diet differs from the nestlings – adults tend to choose medium size, and especially Diptera, prey to feed their young, self-feeding on orders that might be more difficult to ingest like Coleoptera (for their hard exoskeleton) and Hymenoptera (bees and wasps, for example, can be particularly dangerous because of their stings) (Turner 1982, 2010).

This was also highlighted in our study, with the results showing Diptera as the most consumed order during the nestlings' development (65%). The ligature method applied on nestlings to recover prey information was, as in our study, also used on data collected in Denmark during the 90's (Møller 2001). The results, similar to ours, showed that the barn swallow's diet was dominated by Diptera (58.1%), with the order Coleoptera representing only 3.8% of the total food; it was also found a high number of Aphidoidea (Hemiptera) with 35.6% of the insects being from this superfamily.

As Diptera was the most significant order in our study, we decided to further examine it. To do so, we identified its items to the family, revealing a high number of different families - 44 identified in total. Of these, Chironomidae was the most abundant, although making up only 24.5% of the order Diptera. The ecological functions of these families were difficult to categorize, as each has different functions and interactions with the ecosystems, sometimes differing with genera. These results heavily suggest that the barn swallow is generalist in its feeding, even in a semi-natural forested habitat.

The data analyses showed that the nestling's food intake along their development seems to be essentially composed by smaller arthropods, between 0 and 8 mm. Despite the size class and biomass appearing to fluctuate according to the age of the nestlings, the mean biomass is stabled around 0.38 ± 0.21 mg. The tests, further supported by the LMM results, imply that despite the apparent selection of different orders, and even different ecological functions of prey, the energy intake is constant, with no significant changes.

This generalist diet of the barn swallow, with different orders and families being preyed throughout the nestling period, may suggest a valuable role of this species in controlling booms of pest insects within the preferred size classes. The large consumption of Isoptera in our study occurs only during a few strict days, at the end of April; this may signify the existence of an Isoptera boom during that time period, to which the barn swallow took advantage. These results are supported by the study of Beal (1918) *in* Turner (2010) that verifies large quantities of the same insect in a barn swallow stomach. Ceia and Ramos (2016) reviewed the role of birds in the control of pests in the *montado*, where they noticed that having a fairly generalist diet is important in pest control, as birds will feed on the most abundant prey, and therefore on pest outbreaks.

To our knowledge, this is the first study on the barn swallow's diet in the *montado*. The feeding habits are similar to those observed in other habitats, with Diptera and Hemiptera as the most consumed orders. The study showed the diversity of arthropods (e.g. Hemiptera, Isoptera, Lepidoptera, Neuroptera, Trichoptera) existing in the *montado*, highlighting the biodiversity of this habitat.

One of the greatest threats to the *montado* are the insect pests, usually very specific species of Coleoptera and Lepidoptera (Pereira *et al*. 2015; Ceia and Ramos 2016). These orders appear in very low numbers on the barn swallows' diet, meaning that the role of this species as controller of *montado's* pests is negligible. Nevertheless, they are still a valuable resource in the system by maintaining the equilibrium of all the other species they consume and, subsequently, the *montado* itself. We can't completely discard, either, the possibility of the importance that these hirundine populations have on insect booms, by preying on the most abundant and consequently reducing their numbers and the possible consequences these could have, even if they are not a direct threat to the ecosystem.

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Annexes

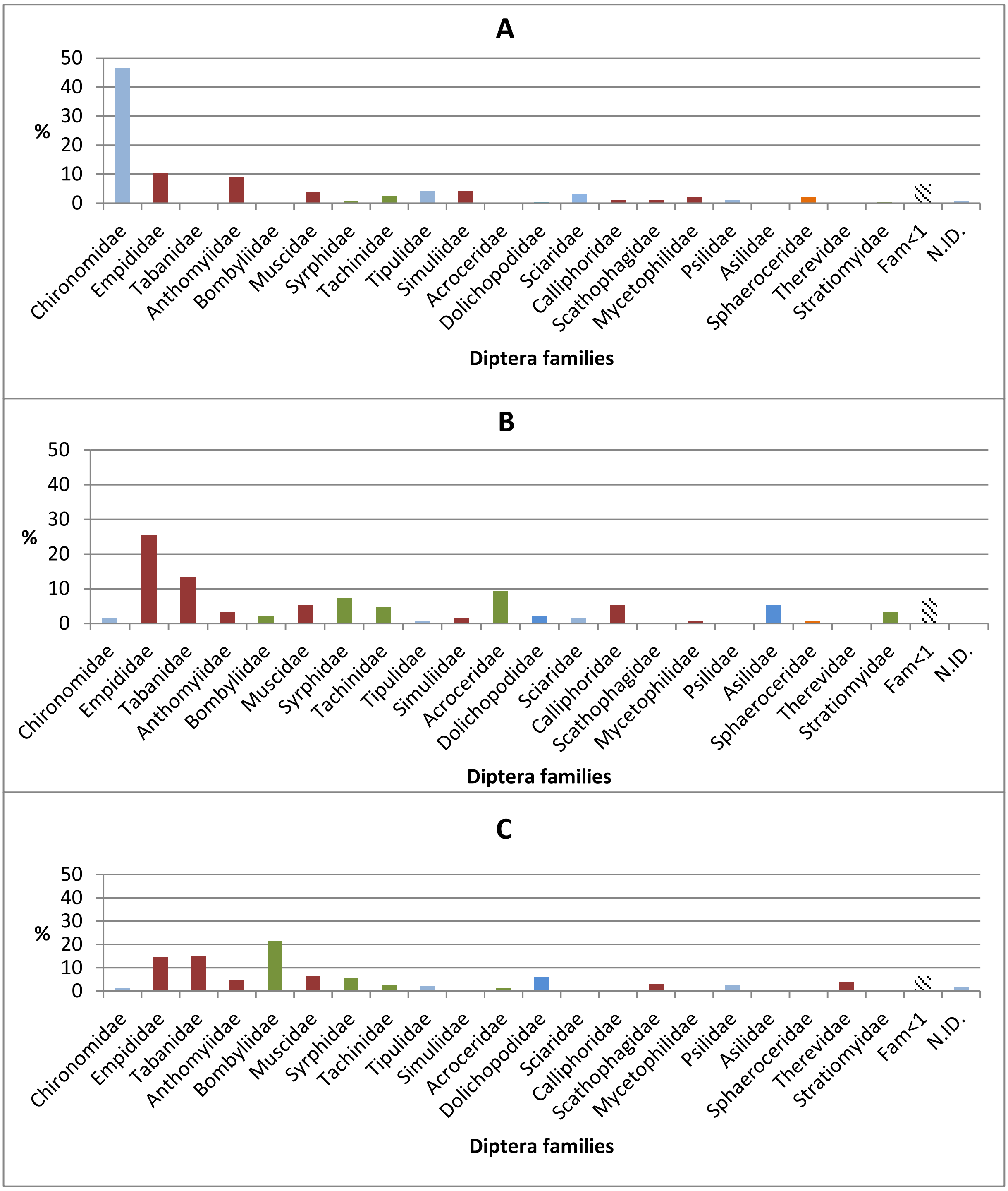
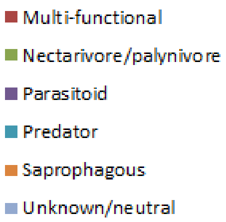


Fig. 8. Percentage of Diptera families in barn swallow's diet during: A - Period 1 (19-30 of April; n=354), B – Period 2 (1-19 of May; n=150) and C – Period 3 (20-31 of May; n=187); Fam<1 comprises the sum of all the families below 1% (when n=691).



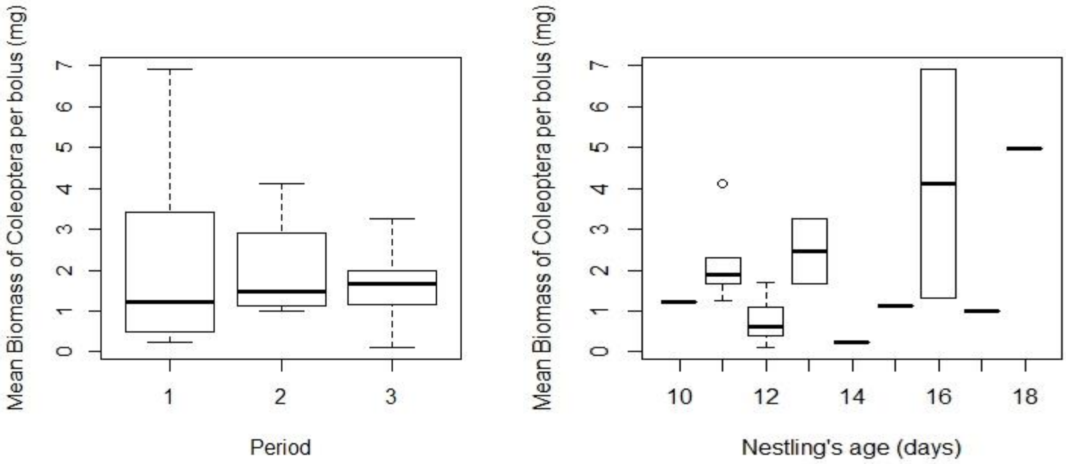


Fig. 9. Mean biomass of the order Coleoptera per bolus in each period – 19-30 April (1), 1-19 May (2), and 20-31 May (3) – and according to nestlings' age (days old).

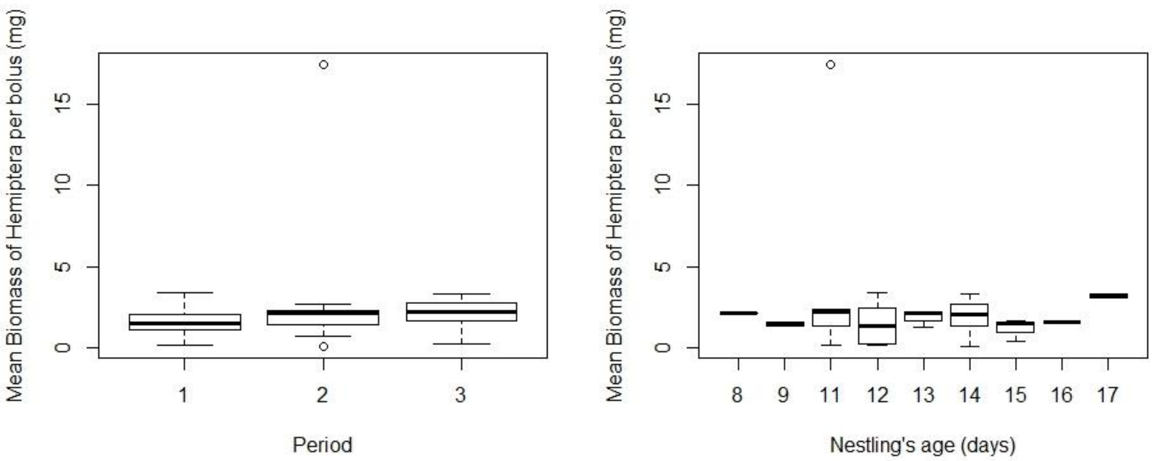


Fig. 10. Mean biomass of the order Hemiptera per bolus in each period – 19-30 April (1), 1-19 May (2), and 20-31 May (3) – and according to nestlings' age (days old).

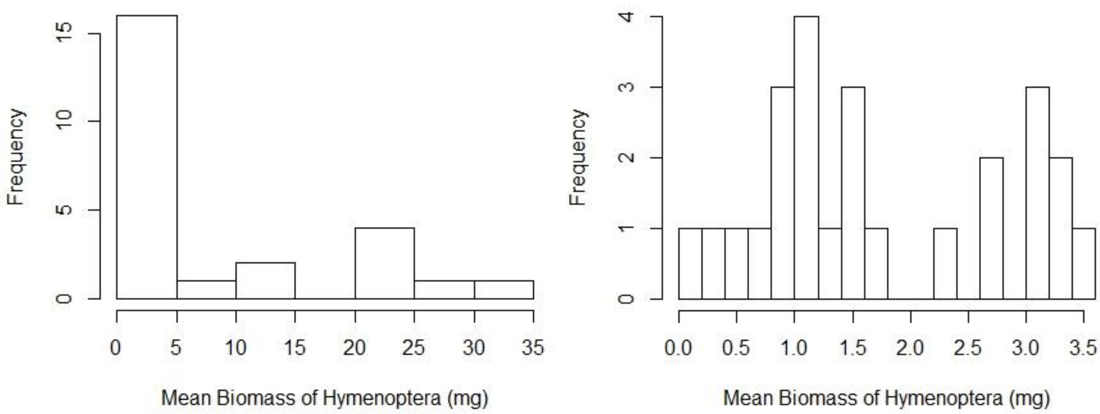


Fig. 11. Mean biomass of the order Hymenoptera before (left) and after (right) log10 transformation.

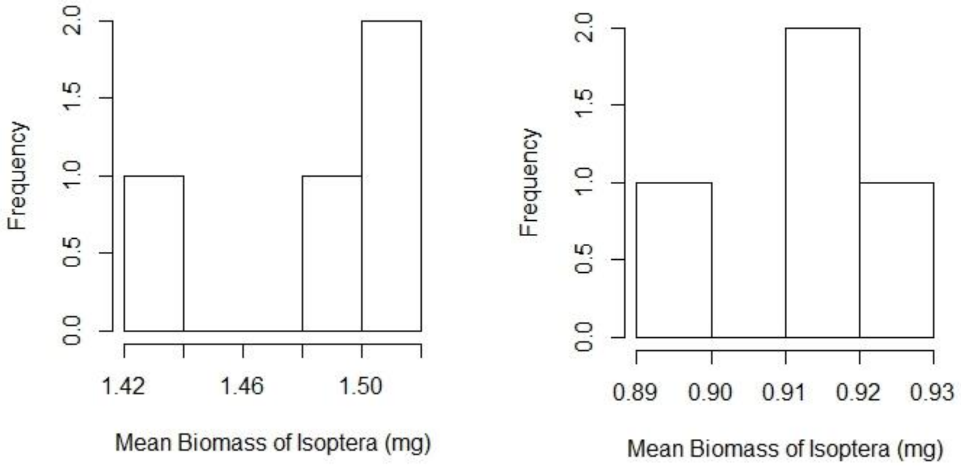


Fig. 12. Mean biomass of the order Isoptera before (left) and after (right) log10 transformation.

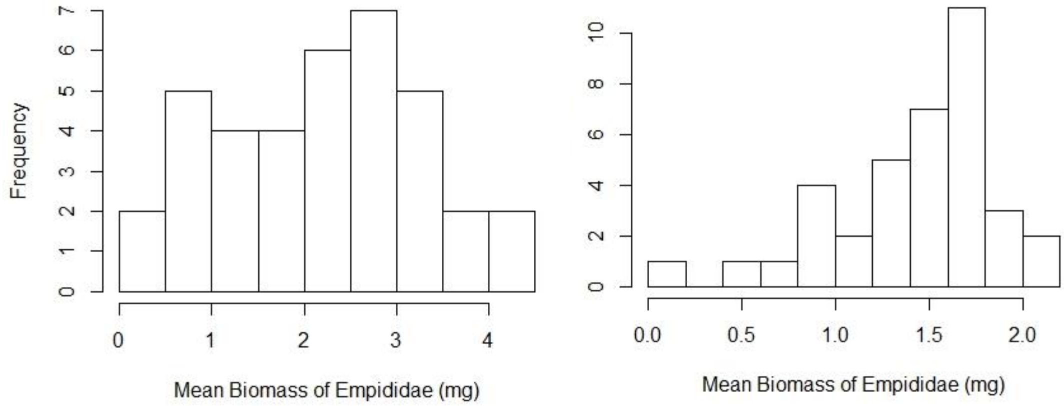


Fig. 13. Mean biomass of the family Empididade before (left) and after (right) square root transformation.

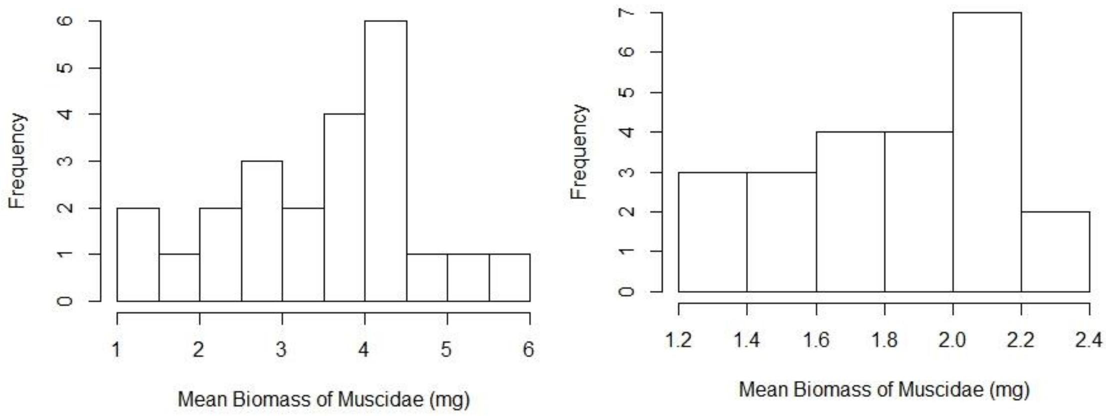


Fig. 14. Mean biomass of the family Muscidae before (left) and after (right) log10 transformation.

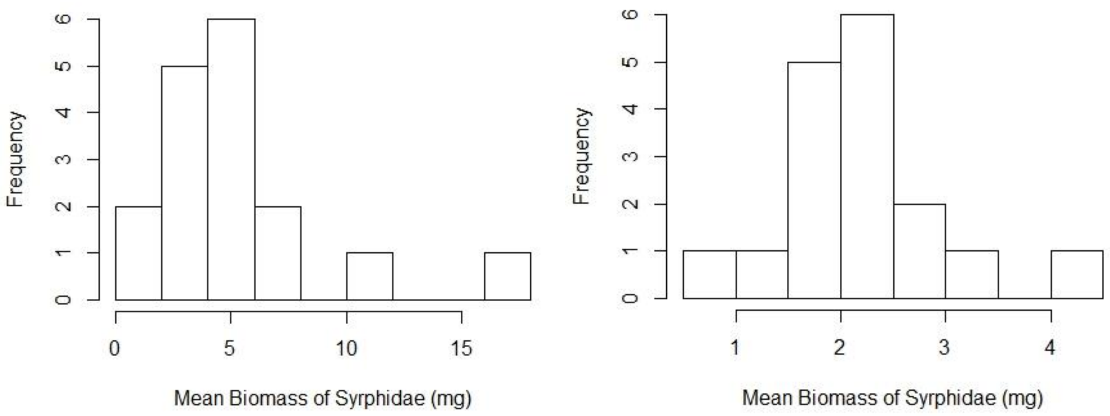


Fig. 15. Mean biomass of the family Syrphidae before (left) and after (right) square root transformation.

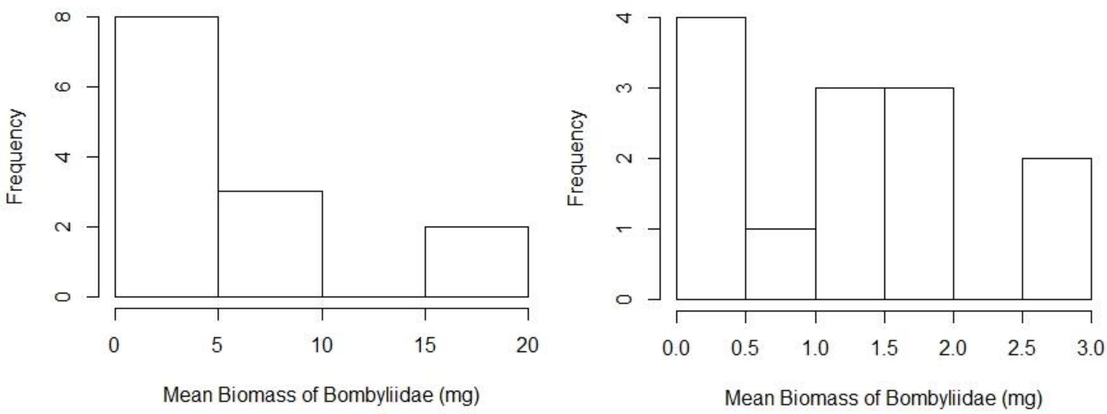


Fig. 16. Mean biomass of the family Bombyliidae before (left) and after (right) log10 transformation.

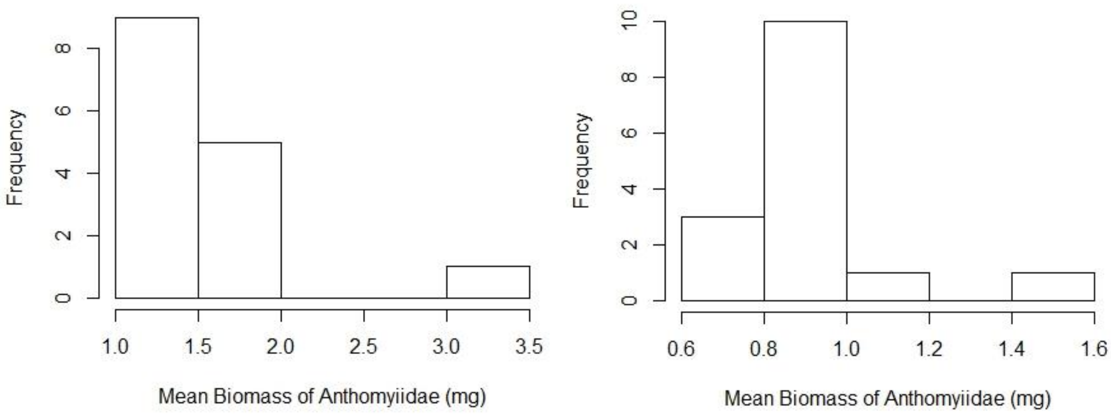


Fig. 17. Mean biomass of the family Anthomyiidae before (left) and after (right) log10 transformation.

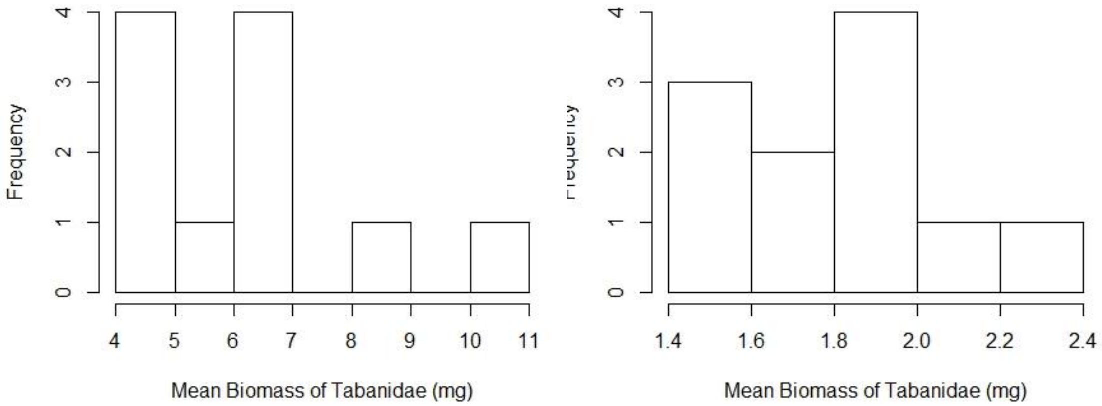


Fig. 18. Mean biomass of the family Tabanidae before (left) and after (right) log10 transformation.