



Campus Diepenbeek
Universiteit Hasselt
Agoralaan Gebouw D
3590 Diepenbeek

Is there enough food for the nightjar (*Caprimulgus europaeus*) in Bosland?

Promotor: Prof. dr. Natalie Beenaerts
Supervisor: Ward Hamaekers

Bachelor thesis by: Ebe Verheyen
To obtain the degree of: Bachelor in Biology
Academic year: 2020-2021

Abstract

Onderzoek naar de afname van insectenpopulaties krijgt steeds meer aandacht. Deze afname blijkt echter niet consistent te zijn tussen verschillende biogeografische regio's in Europa. Lokale studies naar het insectenaanbod zijn daardoor van groot belang. Dit onderzoek focust op de voedselbeschikbaarheid voor de nachtzwaluw (*Caprimulgus europaeus*) in Bosland. Aan de hand van lichtvallen, geplaatst tijdens de zomer van 2020, werd het aanbod nachtvlinders in verschillende biotopen geanalyseerd. Bovendien werd er gezocht naar een statistisch model om op een efficiënte manier de biomassa te schatten. In totaal werden er vijf verschillende habitats onderzocht, waarbij telkens twee lichtvallen werden geplaatst per habitat. Het aanbod nachtvlinders varieerde in de tijd. Over het algemeen was het aanbod het grootst in droge heide en naaldbos habitats. Naast interspecifieke variatie in aantallen en biomassa, werd er ook intraspecifieke variatie aangetroffen tussen de biotopen. Omwille hiervan, is het moeilijk te concluderen welke redenen er zijn voor deze variatie. In tegenstelling tot eerder onderzoek, werden er geen significante allometrische trends gevonden tussen het lichaamsgewicht en lineaire afmetingen van de nachtvlinders. Verfijnde regressiemodellen toegepast op familieniveau bleken al veelbelovend, in het bijzonder voor vergelijkende studies. Het is daarom zeker aangewezen om hier verder onderzoek naar uit te voeren.

Inhoudsopgave

1.	Introduction	1
2.	Material and methods	3
2.1	Research area.....	3
2.2	Nightjar.....	5
2.3	Moths.....	5
2.4	Samples	6
2.5	Sampling sites.....	7
2.5.1	<i>Dry heathland</i>	7
2.5.2	<i>Coniferous forest</i>	7
2.5.3	<i>Valley</i>	7
2.5.4	<i>Dunes</i>	7
2.5.5	<i>Agricultural area</i>	7
2.6	Measurements and statistical analysis	7
3.	Results	9
3.1	Size range	9
3.2	Preliminary statistical analysis	9
3.3	Nonparametric least squares regression	11
3.4	Simple and multiple linear regressions	12
4.	Discussion	13
5.	Conclusion.....	15
6.	Acknowledgements	16
7.	References	17

1. Introduction

The European nightjar (*Caprimulgus europaeus*) is a crepuscular insectivore, typically found in transition zones between different biotopes or mosaic landscapes. *C. europaeus* has a large distribution area within Europe. However, since the 1950s, there have been severe population declines in several areas, notably in the western and northwestern parts of the continent. This decrease is essentially associated with habitat changes caused by agricultural and forestry intensification (MORRIS et al., 1994; BOWLER et al., 2019). Nonetheless, in recent years, populations have increased in several Western European countries (VERSTRAETEN et al., 2011; EVENS et al., 2017a). In Flanders, the nightjar is categorized on the Red List as 'almost in danger' (DEVOS et al., 2016), and in Belgium, management works are dedicated to its habitat restoration (VERHEYEN et al., 2013; BLONDEEL & VANGANSBEKE, 2016).

This migratory bird reaches its breeding areas in Western Europe in early May (EVENS, et al., 2017b). Here, it breeds on dry soils, and during the 4-month breeding season, it is mainly found in open semi-natural habitats such as pine forests and glades in deciduous forests (SIERRO et al., 2001). The primary habitat types are characterized by structured (wet or dry) heathland, with the presence of scattered trees such as birch (*Betula* sp.), Scots pine (*Pinus sylvestris*), and Corsican pine (*Pinus nigra*). The transition to open spaces is an important element (BERRY, 1979). Nightjars can occur in other habitats when these primary habitats are absent or degraded. The secondary habitats can be found in Bosland, the study area of this research. Typical characteristics are coniferous wood, clearings, and plains.

The presence of open areas is particularly important in a nightjar territory (BEYEN, 2000). Nightjars hunt at dusk and at night (JETZ et al., 2003). They have no echolocation or good hearing, but morphological and physiological adaptations to optimize their hunting techniques. HOWES (1978) and SCHLEGEL (1969) provide an extensive review on this topic. Their diet mainly consists of moths (Lepidoptera), and beetles (Coleoptera) (SCHLEGEL, 1969; VAN KLEUNEN et al., 2007). However, the food composition mainly depends on the supply. The availability of nocturnal insects differs per biotope, year, season, temperature, and humidity, but also according to the reproduction time of the insects (SCHLEGEL, 1969; SIERRO et al., 2001; JONASON et al., 2014). Foraging behavior is strongly influenced by the amount of light. To have sufficient light, the nightjar will hunt mainly during morning and evening twilight and clear nights (TODD et al., 1998; JETZ et al., 2003). BRIGHAM & BARCLAY (1992) showed that in related species, prey smaller than 5 mm was not detected. Frequent unfavorable light conditions limit the foraging time, making the nightjar highly dependent on high densities of large prey (TODD et al., 1998). The heat produced by microclimates such as dunes and roads attracts insects. Transition zones between habitat types are remarkably suitable foraging areas because here, microclimates interact strongly (BERRY, 1979). Changes in vegetation can cause major shifts in the nightjar's food supply. Anthropogenic influences and natural processes greatly affect the availability of suitable foraging and breeding areas. The form and intensity of recreation largely determine the chance of disturbance. Habitat degradation and fragmentation through urbanization and intensive agriculture can make it difficult to reach suitable foraging areas (MARÉCHAL, 1989; LILEY & CLARKE, 2003).

In Bosland, the existing traffic infrastructure and urban areas cause fragmentation of the landscape (Agentschap voor Natuur en Bos, 2014). The low availability of foraging habitats near breeding sites increases foraging distance (EVENS et al., 2018). Nightjars were found up to 5.6 km outside their breeding territories to hunt. These foraging areas are characterized by

extensively cultivated grasslands and recreational areas associated with moderate levels of human activities (EVENS et al., 2017a). Although management works have resulted in an increase in nightjar populations in recent years (VERSTRAETEN et al., 2011), it is important to include the heterogeneity of the landscape, because it can influence food availability, and therefore, population dynamics of insectivorous birds (EVENS et al., 2018).

This study focuses on food availability in different foraging areas in Bosland. The decline in populations of avian aerial insectivores, such as the nightjar, could be due to the loss of their prey (SMITH et al., 2015; NG, et al., 2018). However, insect decrease is inconsistent among biogeographical regions in Europe, making local studies examining the insect supply all the more important. For this research, I focused on moths (Lepidoptera), as they would be the primary food source of nightjars (SIERRO et al., 2001; VAN KLEUNEN et al., 2007; EVENS et al., 2020). The supply of nocturnal insects in different habitats was determined using light traps. The locations were based on visual confirmation of foraging nightjars. Typical foraging sites are forest edges, and they have also been observed hunting above open sandy soils and heath.

The assessment of available aerial insects in different locations in Bosland is imperative to understand bird population dynamics, and insights allow for targeted management. Biomass can be a useful indicator for processes causing a change in insect communities. In this study, I examine whether some biotopes have a higher supply of moths compared to others and possible explanations for this. Furthermore, I explore ways to calculate biomass. Insect measurements can be time-consuming, impractical, or impossible. Therefore, calculations of biomass are cost and time effective. Length-mass regression is a common technique for estimating biomass from samples. However, there are very few published regression equations for adult Lepidoptera. I try to establish a statistical model using a minimal number of measurements and ascertain its accuracy in estimating dry biomass.

2. Material and methods

2.1 Research area

In 2005 Bosland was founded as a forest project by the municipality of Hechtel-Eksel, the city of Lommel and Agentschap voor Natuur en Bos. Meanwhile, the partnership has seven members; the municipality of Overpelt, the city of Peer, Regionaal Landschap Lage Kempen, and Toerisme Limburg have joined the project over the years (Bosland, 2012). Bosland is located in the northwest of the province of Limburg. The area of 22,000 ha extends over the Bosland municipalities (**Figure 1**). Except for Peer, there is a main entrance gate in each of these municipalities (OPSTAELE & BERTEN, 2013).

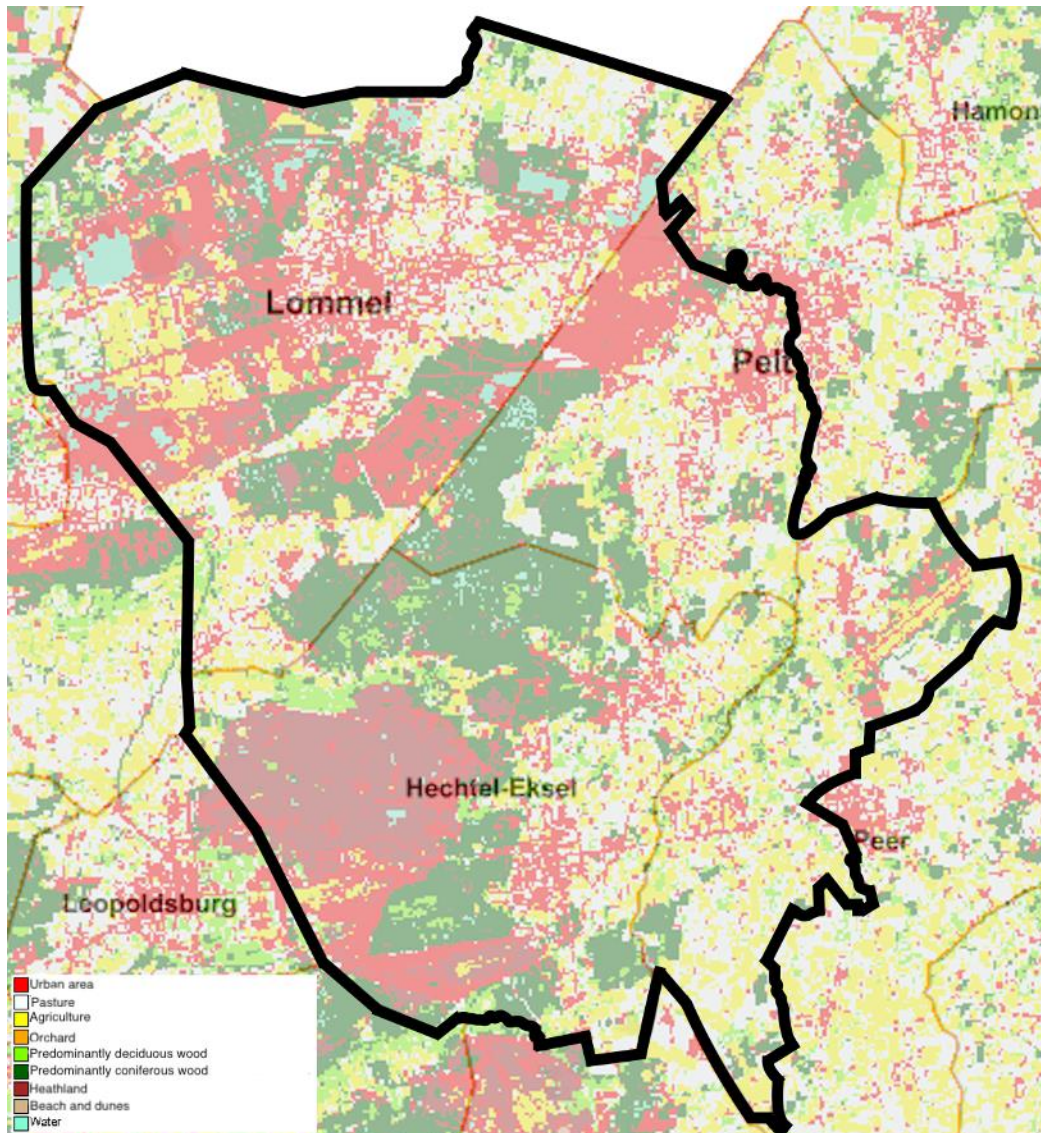


Figure 1 Overview map of Bosland (Soil coverage file, recording 2001 – Agentschap Informatie Vlaanderen)

Bosland is located on the northwestern spur of the Kempen plateau and is dominated by characteristic poor sandy soils. The open space consists of alternating valley areas, forests, heathland, agricultural zones, open land dunes, and ponds (Bosland, 2012). The existing traffic infrastructure and urban areas cause fragmentation of the landscape. Fragmentation also occurs between Bosland and surrounding nature reserves, such as Nationaal Park Hoge Kempen and various valley areas (of the Grote Nete, Kleine Nete, ...), but also Dutch nature reserves such as De Plateaux and Stevensbergen (Agentschap voor Natuur en Bos, 2014).

Bosland includes several subareas. For this research, the focus is on Domeinbos Pijnven, located in the municipalities of Hechtel-Eksel and Lommel. The forest reserve areas are Pijnven Bos, Pijnven Ven and De Vriesput (**Figure 2**). The total domain forest covers 934 ha and is mainly dominated by coniferous wood (91%). Corsican pine forms the main tree species (59%), followed by Scots pine (35%). Heathland covers the majority of open spaces. The area also includes some shifting dunes and three fens (WATERINCKX & ROELANDT, 2001; OPSTAELE & BERTEN, 2013). Despite the main economic function of the forest complexes, management works in the subareas of Bosland are mainly dedicated to habitat restoration for the nightjar (VERHEYEN et al., 2013; BLONDEEL & VANGANSBEKE, 2016). In Domeinbos Pijnven, broad, undulating trails have been constructed. Clear-cuttings and sod-cuttings have been applied to restore land dunes. A fen restoration has also been carried out and in the north of the domain forest, a sparse grassland “De Vlinderwei” has been created (OPSTAELE & BERTEN, 2013).



Figure 2 Situation of the three forest reserve areas of the Pijnven: A – De Vriesput, B – Forest, C – Fen (Streetmap).

Different habitat types can be found in the forest reserve areas (OPSTAELE & BERTEN, 2013).

Heathland: Wet heathland (habitat type 4010) is distributed scarcely around the edges of the central fen but is widespread in De Vriesput. Species composition is determined by groundwater availability and management works. The number of species is limited; Purple Moor-grass (*Molinia caerulea*), Bog Heather (*Erica tetralix*), and Scotch heather (*Calluna vulgaris*) are the dominant species. Dry heathland (habitat type 4030) occurs only fragmented but is more common in De Vriesput. This type of vegetation consists of formations of evergreen dwarf shrubs, dominated by Scotch heather. In De Vriesput, transitional forms of heathland occur.

Semi-natural grassland (habitat type 6230): This habitat type can only be found in De Vriesput and fragmented along different trails. Grasses like matgrass (*Nardus stricta*), *Danthonia decumbens*, Purple Moor-grass, and *Agrotis* sp. dominate, but herbs and heath shrubs can also be found.

Oak forest (habitat type 9190): Around the central fen a poorly developed form occurs. It still has a fairly large proportion of American oak (*Quercus rubra*). Characteristic is a poor, weakly developed shrub layer. Typical species are English oak (*Q. robur*), common silver birch (*Betula pendula*), and downy birch (*B. pubescens*), but also mountain ash (*Sorbus aucuparia*) and aspen (*Populus tremula*).

Valley forest (habitat type 91E0): The subtype oligotrophic woodland occurs along and south of the Balengracht. It is a mixed forest with pines and oaks. The alternation of open water, marsh vegetation, and scattered black alder (*Alnus glutinosa*) is a typical feature. South of the central fen, a more nutrient-rich type occurs as a less developed deciduous forest with few typical species.

Freshwater (habitat type 3130): In the central fen and De Vriesput there is shallow, stagnant water. The fen mainly extracts groundwater and is therefore mesotrophic. The oligotrophic type can also be found there (habitat type 3110). Typical species are American shoreweed (*Littorella uniflora*) and quillworts (*Isoetes* sp.).

2.2 Nightjar

The European nightjar (*Caprimulgus europaeus*) is a crepuscular insectivore. This migratory bird occurs in Northern and Central Europe during the breeding season and hibernates in Africa (VERSTRAETEN et al., 2011; EVENS et al., 2017b). In Flanders, the nightjar is categorized on the Red List as 'almost in danger' (DEVOS et al., 2016). In recent years, populations have increased in several Western European countries, including Belgium (VERSTRAETEN et al., 2011; EVENS et al., 2017a). The nightjar has a habitat preference for open spaces in young forests. These sites are mostly characterized by heath and mostly coniferous wood (VERSTRAETEN et al., 2011). The species breeds on the ground (SCHLEGEL, 1969; CRESSWELL, 1996), and open spaces are used as breeding sites (BERRY, 1979; VERSTRAETEN et al., 2011). Typical foraging areas are grasslands and rural areas with recreation (EVENS et al., 2017a). The interconnection between different habitats depends on the heterogeneity of the landscape. This can affect the foraging behavior of nightjars and could increase stress levels when birds occupy sub-optimal breeding areas.

In Bosland, the fragmentation of the landscape reduces the availability of foraging areas around breeding sites. Management works aimed at creating open spaces and restoring foraging areas have a positive influence on the nightjar population (EVENS et al., 2018).

2.3 Moths

The Lepidoptera form a monophyletic order of more than 160,000 described species distributed over 47 superfamilies and 133 families (KRISTENSEN et al., 2007; VAN NIEUKERKEN et al., 2011) of which more than 70 families occur in Belgium (De Prins, 2016). Moths form a paraphyletic group that includes all species within the Lepidoptera except butterflies. In general, they are classified as macro- and micro-moths (KRISTENSEN et al., 2007). The moths and butterflies represent the adult life stage. Moths with wings usually have two pairs. The second thoracic segment (the mesothorax) carries the forewings, and the third segment (the metathorax) carries the hindwings (COMMON, 1990; MILLER & HAMMOND, 2003). Within the Lepidoptera, there is intraspecific variation in the presence, shape, size, and functionality of the wings (MILLER & HAMMOND, 2003; DE CAMARGO et al., 2015). There is often even a characteristic pattern in the flight time of a species, usually in relation to the season (MILLER & HAMMOND, 2003). Moths are an important source of food for the nightjar (VAN KLEUNEN et al., 2007).

2.4 Samples

As the nightjar is a crepuscular bird, an efficient catching method for prey analysis is light traps. By using UV lamps, the catch is representative of the local supply (VAN KLEUNEN et al., 2007; TRUXA & FIEDLER, 2012). Moreover, at night they are relatively insensitive to disturbance because the light is not very noticeable to people (VAN KLEUNEN et al., 2007).

The light traps were set up using 15-Watt UVA lamps. At the bottom a funnel connected to a barrel that contained a solution of ethanol (70%), water (30%), and a few drops of detergent. The trap was connected to a battery and suspended at two meters with a self-made construction (**Figure 3**). In 2020, during the summer months of June, July and August, the traps were hung three times per week at sunset and collected at sunrise. Each time ten light traps were used, spread over five different biotopes. In September, traps were hung only once per week. The locations were selected based on visual confirmation of foraging nightjars (**Table 1, Figure 4**).

Table 1 Trap codes and biotopes.

Nb.	NL	EL	Area	Environment	Height
PV03	51,168275	5,336178	Dry heathland	Forest edge – dune heath	2 m
PV04	51,166667	5,331569	Dry heathland	Dry heathland, just opened up	2 m
PV05	51,166917	5,324097	Coniferous forest	Forest road, in Scots pine	2 m
PV06	51,169522	5,325394	Coniferous forest	Forest road, in Scots pine	2 m
PV08	51,160386	5,325764	Valley	Wet meadow, along a stream	2 m
PV11	51.167356	5.350972	Dunes	Dune area	2 m
PV12	51.166861	5.349361	Dunes	Dune area	2 m
PV13	51.182042	5.319022	Agricultural area	Edge of farmland with low tree line	2 m
PV14	51.181320	5.316572	Agricultural area	Edge of farmland with low tree line	2 m
PV15	51.156659	5.339091	Valley	Stream valley, wet meadow, along a row of trees and reeds	2 m



Figure 3 Setup light trap.

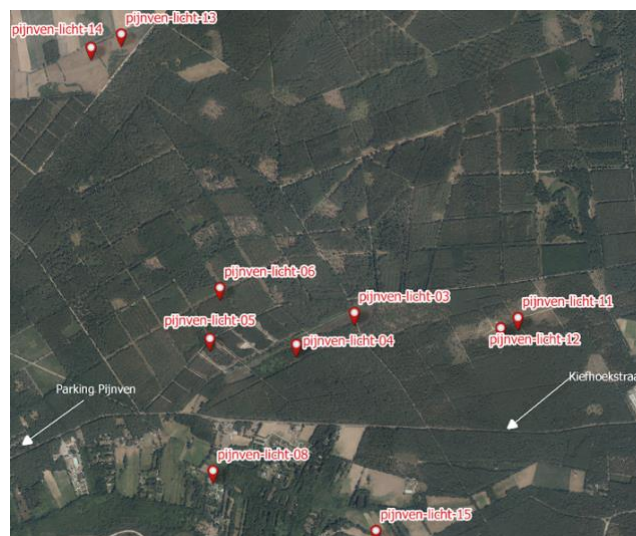


Figure 4 Location of the light traps. Cartographer: Ward Hamaekers.

2.5 *Sampling sites*

2.5.1 *Dry heathland*

PV03 and PV04 (**Table 1**) were placed along the forest edge near dry heathland. PV03 was situated in a biologically valuable Scots pine plantation with low undergrowth of grasses and herbs (Biological Valuation label: ppmh; BOSCH et al., 2006). PV04 was situated in a biologically valuable coniferous plantation with black pine and Scots pine. There was low undergrowth of grasses and herbs, with dominance of the eagle fern (Biological Valuation label: pmh + pinn + pins; BOSCH et al., 2006).

2.5.2 *Coniferous forest*

PV05 (**Table 1**) was located in a complex of biologically valuable and very valuable elements. This is an area with extensive forestation and dry shrubby heath vegetation with spontaneous woody debris on various sites. There is a dominance of eagle fern and birch sp. can also be found here (Biological Valuation label: cg + sz/cp + bet; BOSCH et al., 2006). PV06 was placed in a biologically valuable Scots pine plantation with low undergrowth of shrubs and American oak (Biological Valuation label: ppmb + quer; BOSCH et al., 2006).

2.5.3 *Valley*

PV08 and PV15 (**Table 1**) were placed in a species-rich permanent cultural grassland with a pronounced microrelief. PV08 was situated in a complex with biologically less valuable and valuable elements. The light trap was located in a feral meadow with bramble, near a recreational zone with rows of mixed deciduous trees and dominance of Douglas fir (Biological Valuation label: hp* + uv + kbglm + kbpse; BOSCH et al., 2006). PV15 was placed in a complex with biologically valuable and very valuable elements. It was located in a wet meadow with multiple moats and with few indicative species. Uniform, species-poor vegetation of sedge grass or reed canary grass occur (Biological Valuation label: hpr* + hc^o + k(mr^o); BOSCH et al., 2006).

2.5.4 *Dunes*

PV11 and PV12 (**Table 1**) were both located in complexes of biologically valuable and very valuable elements. These concerns open vegetation with starting forestation. This includes degraded heathland with a dominance of wavy hair grass and limited shrub and tree cover. There is also dry heath vegetation and few tall trees because there are mostly young trees (Biological Valuation label: cdb + cgb; BOSCH et al., 2006).

2.5.5 *Agricultural area*

Both PV13 and PV14 (**Table 1**) were placed on biologically less valuable agricultural fields within a large agricultural area. The fields are located on sandy soils and were surrounded by low rows of trees (Biological Valuation label: bs; BOSCH et al., 2006).

2.6 *Measurements and statistical analysis*

After collecting, the content of the traps was sorted. The different groups of nocturnal insects were stored on ethanol and passed on for determination to Likona. The moths were dried at room temperature for at least five days. As suggested by GARCÍA-BARROS (2015), six linear measurements (in mm) were taken on dried specimens: the length and width of the thorax, abdomen, and forewings. These measurements were used to assess correlations, and to build a model to estimate biomass. Individuals of the same size were processed together. The dry weight was also determined.

The data is analyzed using various nonparametric methods. The relationship between body length and body mass is determined via Spearman's rank and Kendall rank correlation test. The variation of biomass between different biotopes is estimated using the Kruskal-Wallis rank-sum test and pairwise Wilcoxon rank-sum test. The most widely accepted technique for biomass estimation involves regression of dry mass on body length (BENKE et al., 1999). There are numerous compilations of length-mass relationships for terrestrial and aquatic invertebrates (e.g. ROGERS et al. 1976, 1977; SCHOENER 1980; SAMPLE et al. 1993). The data is fit to the power function:

$$W = aL^b$$

where W is dry mass (mg), L is length (mm), and a and b are fitted parameters describing the allometric relationship between these variables. Parameters were fit using nonlinear least-squares regression, with starting values of 0.03 and 3 for a and b respectively. A linear regression model was applied to the dataset. However, the data did not meet the assumptions, resulting in a statistically less significant model. A nonlinear regression would most likely give a significant result, but this is beyond the scope of this study.

3. Results

3.1 Size range

In total, 37,088 individuals were weighed and measured. The dry body mass of the moths covered a range of variation, from 0.3 mg to 0.59 g, corresponding to forewing lengths between 6 mm and 48 mm. The body length varied from 5 mm to 38 mm. **Figure 5** shows the total number of moths captured each date the light traps were hung.

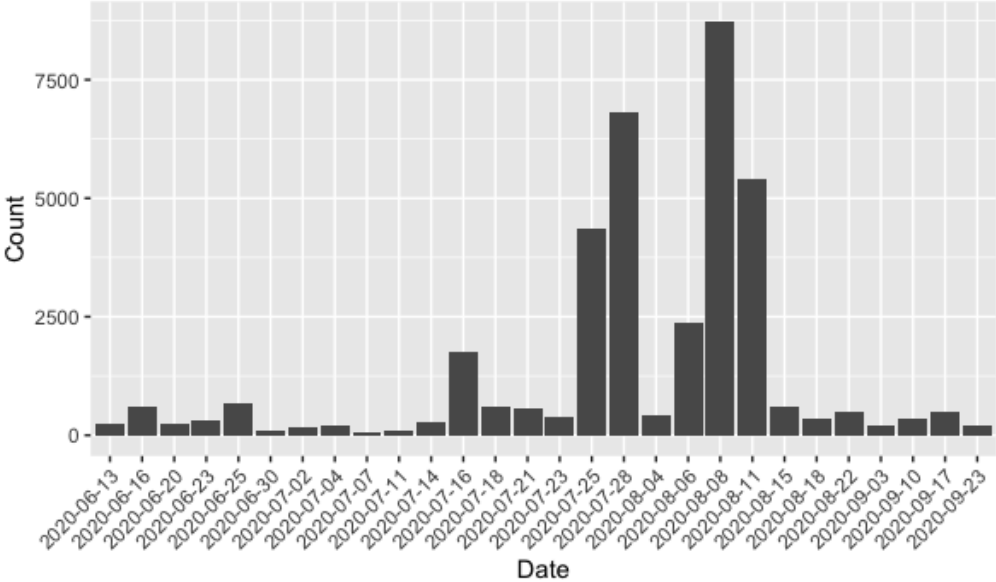


Figure 5 Number of moths by date of light trap collection.

The supply of moths varies over time. This could be explained by different weather conditions, and by the fact that reproductive stages vary between species. **Table 2** represents the mean and standard deviation of the replicated measurements.

Table 2 Estimate of measurement error for dry body weight and six linear measurements. The values given are the mean \pm 1 SD (within individuals, n = 37088).

	Within individuals
Dry weight (DBW)	0.01387629 \pm 0.03023052
Forewing Length (FWL)	15.38913 \pm 3.200898
Forewing Width (FWW)	3.407409 \pm 1.377571
Thorax Length (TL)	3.325334 \pm 0.9111367
Thorax Width (TW)	3.102756 \pm 0.7318396
Abdomen Length (AL)	5.625054 \pm 2.06107
Abdomen Width (AW)	2.303899 \pm 0.9664995

3.2 Preliminary statistical analysis

The relationship between body length and body mass is presented in **Table 3**. The results show a significant strong positive correlation between body length and body mass, based on both Spearman's rank and Kendall rank correlation tests. **Figure 6** shows the trend of body mass over body length in a scatterplot. The line of best fit shows a nonlinear relationship. Biomass also differs between biotopes. The Kruskal-Wallis test was used to check if our independent groups come from populations with the same median. A significant difference was found,

meaning that a post hoc comparison needed to be performed to determine where the difference lies. Using the Wilcoxon rank-sum test (**Table 4**), significant differences were found between almost all biotopes. During the sampling period, both dune areas (PV11, PV12) seem to have a comparable supply of moths. The same applies to the valley and agricultural areas (PV08, PV13, and PV14, PV15).

Table 3 Relationship between body length and body mass based on Spearman's rank and Kendall rank correlation test.

Spearman's rank		Kendall rank	
ρ	P	τ	P
0.7068178	< 0.001	0.6547981	< 0.001

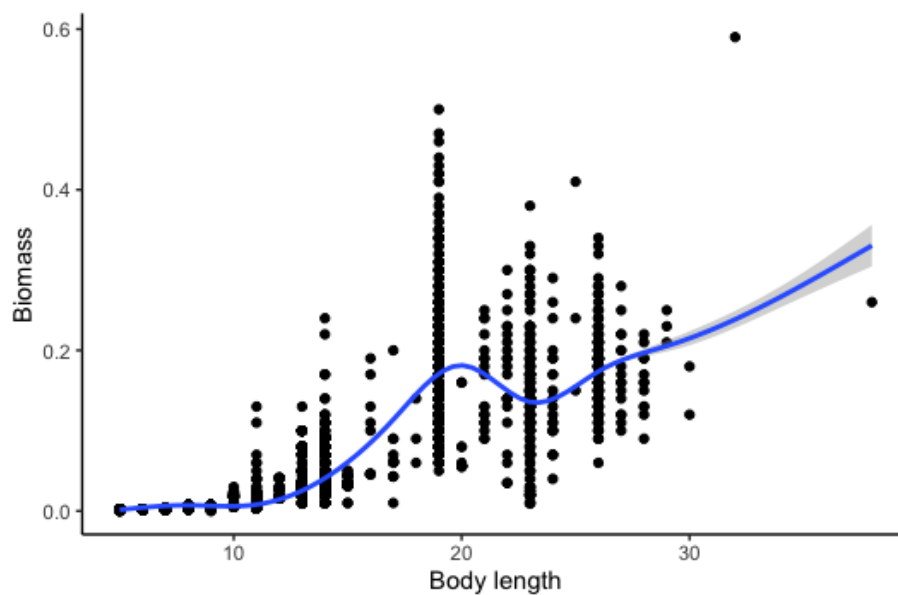


Figure 6 Trend in body mass over body length. Blueline: line of best fit with confidence bands (CI=95%).

Table 4 Pairwise comparisons of the different biotopes using the Wilcoxon rank-sum test. Values in bold are those with $P > 0.05$. P-value adjustment method: Benjamini & Hochberg. Kruskal-Wallis: $\chi^2 = 2506.4$, $df = 9$, $P < 0.01$.

	PV03	PV04	PV05	PV06	PV08	PV11	PV12	PV13	PV14
PV04	0.0047	-	-	-	-	-	-	-	-
PV05	< 0.01	< 0.01	-	-	-	-	-	-	-
PV06	< 0.01	< 0.01	< 0.01	-	-	-	-	-	-
PV08	< 0.01	< 0.01	< 0.01	< 0.01	-	-	-	-	-
PV11	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	-	-	-	-
PV12	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	0.4581	-	-	-
PV13	< 0.01	< 0.01	< 0.01	< 0.01	0.9337	< 0.01	< 0.01	-	-
PV14	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	-
PV15	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	0.0507

Figure 7 shows the total count of moths per biotope. Dry heathland (PV03) and coniferous forest (PV05) have the highest abundance.

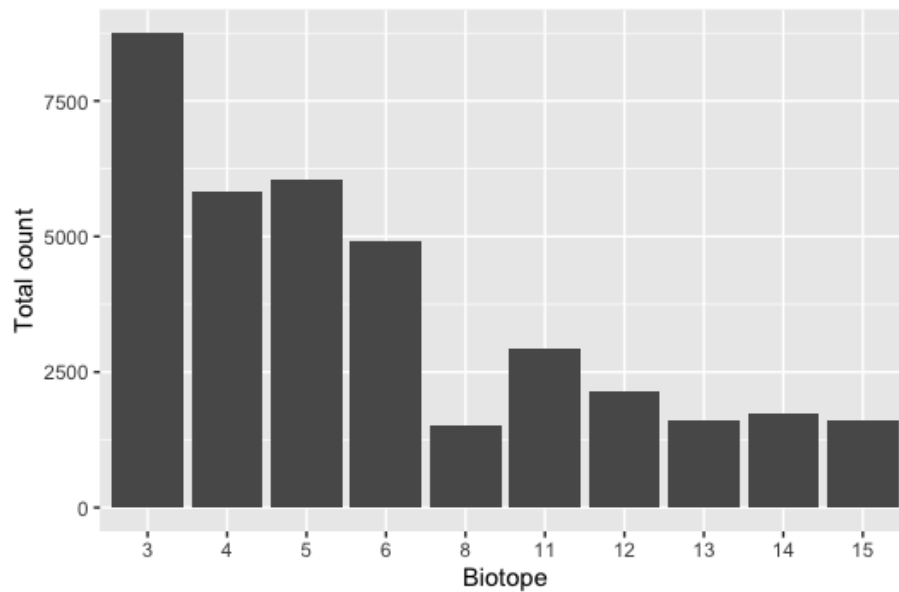


Figure 7 Total moth count per biotope.

In comparison, **Figure 8** shows the total biomass of moths per biotope. Dry heathland (PV03) and coniferous forest (PV05) also have the highest biomass.

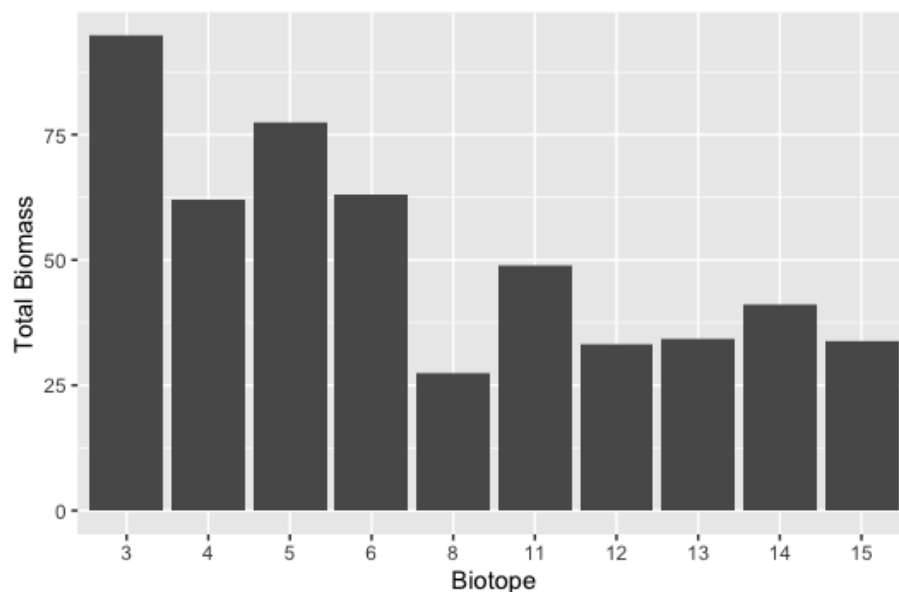


Figure 8 Total moth biomass per biotope.

3.3 Nonparametric least squares regression

To perform a nonparametric least squares regression, the moths were initially classified into size classes (**Table 5**). However, as the relationship between body length and biomass is not linear, the parameters for the power function could not be fitted to each class. For this reason, the parameters were fitted to the data as a whole.

Table 5 Size classes used for classification of moths

	Class 1	< 12.5 mm
12.5 mm ≤	Class 2	< 15 mm
15 mm ≤	Class 3	< 17.5 mm
17.5 mm ≤	Class 4	< 20 mm
20 mm ≤	Class 5	< 22.5 mm
22.5 mm ≤	Class 6	< 25 mm
25 mm ≤	Class 7	< 27.5 mm
27.5 mm ≤	Class 8	

After fitting the parameters for the power function, a comparison was made between the estimated and weighed biomass using the Wilcoxon rank-sum test. **Table 6** shows the estimates and standard error for the parameters.

Table 6 Parameter estimates for regression of length (mm) on dry mass (mg). $P < 0.01$.

	a (SE)	b (SE)
Lepidoptera	0.034020 (0.000884)	2.673761 (0.008647)

To determine how accurate the model estimates the dry biomass, the Wilcoxon rank-sum test was performed to compare the weighed and estimated values ($W = 230760000$, $P < 0.01$).

3.4 Simple and multiple linear regressions

The results from simple and multiple linear regressions of DBW and the other variables are presented in **Table 7** (based on species means, all $R > 0.45$). While keeping in mind that the results are not significant, regression of the different variables shows that other dimensions than body length might also influence body mass.

Table 7 Relationships between dry body weight and the test variables, estimated both by simple linear regression (left four columns) and in a multiple linear regression model (right three columns; intercept = -0.0505314, multiple $R = 0.6949$, adjusted $R^2 = 0.6949$). The β values represent the relative contribution of each variable in the multivariate model.

Variable	Simple linear regression				Multiple linear regression		
	R	Slope	P	Intercept	β	Slope	P
FWL	0.5678	0.0071	<0.001	-0.0956	0.3485	0.0033	<0.001
FWW	0.4544	0.0148	<0.001	-0.0365	-0.0010	-0.0002	0.250
TL	0.4857	0.0231	<0.001	-0.0630	-0.2556	-0.0085	<0.001
TW	0.4589	0.0280	<0.001	-0.0729	-0.3340	-0.0138	<0.001
AL	0.6622	0.0119	<0.001	0.0533	1.0468	0.0154	<0.001
AW	0.5064	0.0223	<0.001	-0.0374	-0.0117	-0.0004	0.262

4. Discussion

In recent years, evidence of declines in insect populations received a considerable amount of scientific attention. However, this decrease is inconsistent among biogeographical regions in Northern and Eastern Europe (PILOTTO et al., 2020). Urbanization stresses biodiversity in the city, but also rural areas. This causes changes in community structures, diversity, and abundance over time, showing the buffering capacity of urban areas (BANG JR., 2010). Insect abundance is used more frequently as the response variable in community analysis. However, insect biomass is strongly correlated with metabolism and is, therefore, a better indicator of the functionality of a species within a community than insect abundance. Biomass may provide more insights into processes causing a change in insect communities. Especially when dealing with poor abundance, insect biomass can be a useful indicator in community studies (SAINT-GERMAIN et al., 2007).

Dry heathland (PV03, PV04) and coniferous forest (PV05, PV06) had the highest abundance of moths. However, when looking at biomass, dry heathland (PV03), coniferous forest (PV05), dunes (PV11), and agricultural area (PV13) had the largest abundance. A pairwise comparison of the biotopes indicates interspecific variation in biomass. This could be due to the difference in habitat structure. However, there is also intraspecific variation. Further research could provide more insights as to why this variation occurs, but due to this large intraspecific variation compared to the interspecific variation currently, no conclusive inferences on habitat and abundance of insects can be drawn.

Because of the high correlation between the different dimensions and body mass of moths, a statistical model might be more efficient to estimate biomass than individual measurements. When analyzing the dataset as a whole, it is clear that the relationship between the body length and biomass of moths is not linear. However, this also applies when classifying the moths into size classes. For this reason, the parameters for the power function could not be fitted to each class. The power function appears to be very inaccurate when applied to the dataset as a whole. The development of unique power functions for Lepidopteran families might increase the accuracy, as research suggests the coefficients of determination (R^2) for length-mass relationships generally increase with increasing taxonomic specificity (SABO et al., 2002). Moreover, as there was no clear relationship between the biomass and the measurements, the selection of a regression model was not possible. Here, too, the determination of moths at a family level might result in a more pronounced relationship between the parameters, allowing the construction of an appropriate model.

GARCÍA-BARROS (2015) found a slightly negatively allometric trend between body weight and single linear measurements, implying comparatively lighter bodies at the largest body sizes and relatively heavier ones at the shortest body size for macro moths ($> 19\text{mm}$). However, this trend could not be concluded from the data. Noteworthy is that macro moths only made up 1,5% of all individuals captured and that this trend was not found in micro moths either. They also found that the multivariate approaches presented high R^2 scores for a much wider range of size, morphology, and taxonomic variety than that in any former comparable study on Lepidoptera. This could mean that a refined regression model could be a useful tool for comparative work in wide taxonomic scopes. Moreover, the performance of a regression model at predicting moth biomass could even be more accurate than the power function. After metamorphosis from a caterpillar to an adult, species with fully developed wings can fly (MILLER & HAMMOND, 2003), meaning factors such as reproduction period and growth rate of the adult must be taken into account. Furthermore, the period for flight may be characteristic for a species, both daily and

seasonally. This means the daily rhythm and the seasonal pattern are two temporal components that influence flight behavior. However, research shows that the time of season and the length of time for the flight period of a species may exhibit a diagnostic pattern (HOLYOAK et al., 1997), and this can be included in a regression model.

Further investigation is needed on length-mass relationships within the Lepidoptera. Nevertheless, I think the performance of the regression models is very promising. When either using more advanced statistical methods or more taxonomically specific groups, a statistical model may indeed provide a very accurate tool for predicting the biomass of adult Lepidoptera.

5. Conclusion

Based on the comparative study of different biotopes in Bosland, no conclusion can be drawn as to which one would have the highest abundance of moths. Due to intraspecific variation between sites, differences between sites cannot be attributed to specific environmental variables that might influence the amount of Lepidoptera found in each habitat. Contrary to previous research, no significant allometric trends between body weight and single linear measurements were found. However, this could be due to the fact that the statistical analyses were carried out based on size classes, rather than families. In addition, a multivariate approach could not be implemented. Nonetheless, regression models proved to be promising in comparable studies. Therefore, pursuing refined regression models for the accurate prediction of biomass at a family level is certainly advisable.

6. Acknowledgements

First and foremost, I would like to thank my promotor Prof. dr. Natalie Beenaerts for their excellent guidance. Thank you for your patience and your positivity. Furthermore, I would like to thank you for answering all my questions, improving my texts, and providing me with useful perspectives. I also wish to thank my supervisor Ward Hamaekers for collecting the light traps, his great help in sorting them, and the guidance he gave me. Thank you for answering my many questions and improving my Material and Methods. I would also like to thank you for the useful information you provided me.

7. References

- Agentschap voor Natuur en Bos. (2014). Ontsnipperingsplan Bosland.
- BANG JR., C. (2010). Effects of Urbanization on Arthropod Diversity, Community Structure and Trophic Dynamics. [Doctoral dissertation, Arizona State University].
- BENKE, A., HURYN, A., SMOCK, L., & WALLACE, J. (1999). Length-mass relationships for freshwater macroinvertebrates in North America with particular reference to the southeastern United States. *Journal of the North American Benthological Society*, 18:308-343.
- BERRY, R. (1979). Nightjar habitats and breeding in East Aglia. *Bird study*(70), 207-218.
- BEYEN, D. (2000). Bosbeheer en biodiversiteit. *Bosbeheer en Nachtzwaluwen*. De boskrant, pp. 30:5-10.
- BLONDEEL, H., & VANGANSBEKE, P. (2016). Biodiversiteit, recreatie en biomassaproductie in Vlaamse bossen: hand in hand of neus aan neus? *BOSrevue*55 1 [jan-feb-maa 2016] Studentenscriptie: winnaar van de Toekomstboom 2015 De Toekomstboom wordt jaarlijks uitgereikt aan de beste studentenscriptie. *Bosreveu*(55), 1-5.
- BOSCH, H., VAN HOVE, M., DE SAEGER, S., & PAELINCKX, D. (2006). Biologische waarderingskaart, versie 2. Kaartbladen 1-7. Rapport en digitaal bestand. Brussel: Instituut voor Natuur- en Bosonderzoek.
- Bosland. (2012, juni). MASTERPLAN BOSLAND uitdagingen voor de toekomst. Opgehaald van bosland.be:
<https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&cad=rja&uact=8&ved=2ahUKEwj9loTp6dTtAhWQzaQKHWTUA2oQFjAAegQIAxAC&url=http%3A%2F%2Fwww.bosland.be%2Fpublicaties%2Fd1%2F7%2Fmasterplan-boslanduitdagingen-voor-de-toekomstjuni-2012-2.pdf&usg=AOvV>
- BOWLER, D., HELDBJERG, H., FOX, A., DE JONG, M., & BOHNING-GAESE, K. (2019). Long-term declines of European insectivorous bird populations and potential causes. *Conservation Biology*, 33(5):1120-1130.
- BRIGHAM, R., & BARCLAY, R. (1992). Lunar influence on Foraging and Nesting Activity of Common Poorwills (*Phalaenoptilus nuttallii*). *The Auk*, 109(2):315-320.
- COMMON, I. (1990). Structure and Life History. In *Moths of Australia* (pp. 5-28). Brill.
- CRESSWELL, B. (1996). Some aspects of their behaviour and conservation. *British Wildlife*(7), 297-304.
- DE CAMARGO, W., DE CAMARGO, N., CORRÊA, D., DE CAMARGO, A., & DINIZ, I. (2015). Sexual Dimorphism and Allometric Effects Associated With the Wing Shape of Seven Moth Species of Sphingidae (Lepidoptera: Bombycoidea). *Journal of Insect Science*(15(1):107).
- DE PRINS, W. (2016). Catalogus van de Belgische Lepidoptera. Opgehaald van http://www.phegea.org/Documents/CatalogueBelgianLepidoptera_2016.pdf.
- DEVOS, K., ANSELIN, A., DRIESSENS, G., HERREMANS, M., ONKELINX, T., SPANOGHE, G., . . . MAES, D. (2016). De IUCN Rode Lijst van de broedvogels in Vlaanderen 2016. *Natuur.oriolus*(82(4)), 109-112.
- EVENS, R., BEENAERTS, N., WITTERS, N., & ARTOIS, T. (2017a). Study on the foraging behaviour of the European nightjar *Caprimulgus europaeus* reveals the need for a change in conservation strategy in Belgium. *Journal of Avian Biology*(48), 1238-1245.
- EVENS, R., CONWAY, G. J., HENDERSON, I. G., CRESSWELL, B., JIGUET, F., MOUSSY, C., . . . ARTOIS, T. (2017b). Migratory pathways, stopover zones and wintering destinations of Western European Nightjars *Caprimulgus europaeus*. *Ibis*(159), 680-686.

- EVENS, R., BEENAERTS, N., NEYENS, T., WITTERS, N., SMEETS, K., & ARTOIS, T. (2018). Proximity of breeding and foraging areas affects foraging effort of a crepuscular, insectivorous bird. *Scientific Reports*(8:3008).
- EVENS, R., CONWAY, G., FRANKLIN, K., HENDERSON, I., STOCKDALE, J., BEENAERTS, N., . . . ARTOIS, T. (2020). DNA diet profiles with high-resolution animal tracking data reveal levels of prey selection relative to habitat choice in a crepuscular insectivorous bird. *Ecology and Evolution*, 10(23):13044-13056.
- GARCÍA-BARROS, E. (2015). Multivariate indices as estimates of dry body weight for comparative study of body size in Lepidoptera. *Nota lepidopterologica*, 38(1), 59-74.
- GORISSEN, D. (2012). Van arm bos tot rijk land. Een korte geschiedenis van Bosland. *Likona* jaarboek, 6-11.
- HOLYOAK, M., JAROSIK, V., & NOVÁK, I. (1997). Weather-induced changes in moth activity bias measurement of long-term population dynamics from light trap samples. *Entomologica Experimentalis et Applicata*(83), 329-335.
- HOWES, C. (1978). Notes on the food and feeding mechanisms of a Nightjar from Thorne. *Naturalist*, 103:28-29.
- JETZ, W., STEFFEN, J., & LINSENMAIR, K. (2003). Effects of light and prey availability on nocturnal, lunar and seasonal activity of tropical nightjars. *Oikos*, 103(3), 627-639.
- JONASON, D., FRANZÉN, M., & RANIUS, T. (2014). Surveying Moths Using Light Traps: Effects of Weather and Time of Year. *Plos One*(9(3)).
- KRISTENSEN, N., SCOBLE, M., & KARSHOLT, O. (2007). Lepidoptera phylogeny and systematics: The state of inventorying moth and butterfly diversity. *Zootaxa*(1668), 699-747.
- LANGSTON, R. H., WOTTON, S. R., CONWAY, G. J., WRIGHT, L. J., MALLORD, J. W., CURRIE, F. A., . . . SYMES, N. (2007). Nightjar *Caprimulgus europaeus* and Woodlark *Lullula arborea* – recovering species in Britain? *Ibis*(149), 250-260.
- LILEY, D., & CLARKE, R. (2003). The impact of urban development and human disturbance on the number of nightjar *Caprimulgus europaeus* on heathlands in Dorset, England. *Biological Conservation*, 114:219-230.
- MARÉCHAL, P. (1989). Foeragegedrag, voedselkeuze en de relatie met milieuomstandigheden bij Nachtzwaluwen *Caprimulgus europaeus*. *Het Vogeljaar*, 37:345-356.
- MILLER, J. C., & HAMMOND, P. C. (2003). Chapter 2: Lifecycle of Lepidoptera. In *Lepidoptera of the Pacific Northwest: Caterpillars and Adults* (pp. 11-15). Forest Health Technology Enterprise Team.
- MORRIS, A., BURGESS, D., FULLER, R., EVANS, A., & SMITH, K. (1994). The status and distribution of Nightjars *Caprimulgus europaeus* in Britain in 1992. *British Trust for Ornithology, Bird Study*.
- NG, J., KNIGHT, E., SCARPIGNATO, A., HARRISON, A., BAYNE, E., & MARRA, P. (2018). First full annual cycle tracking of a declining aerial insectivorous bird, the Common Nighthawk (*Chordeiles minor*), identifies migration routes, nonbreeding habitat, and breeding sites fidelity. *Canadian Journal of Zoology*, 96(8):869-875.
- OPSTAELE, B., & BERTEN, D. (2013). Beheerplan bosreservaat Pijnven - incl. Vriesput te Lommel en Hechtel-Eksel. Agentschap voor Natuur en Bos.
- PILOTTO, F., KÜHN, I., . . . , & HAASE, P. (2020). Meta-analysis of multidecadal biodiversity trends in Europe. *Nature Communications*, 11(3486).
- ROGERS, L., BUSCHBOM, R., & WATSON, C. (1977). Length-weight relationships of shrub-steppe invertebrates. *Annals of the Entomological Society of America*, 70:51-53.
- ROGERS, L., HINDS, W., & BUSCHBOM, R. (1976). A general weight vs length relationship for insects. *Annals of the Entomological Society of America*, 69:387-389.

- SABO, J. L., BASTOW, J. L., & POWER, M. E. (2002). Length-mass relationships for adult aquatic and terrestrial invertebrates in a California watershed. *The North American Benthological Society*, 21(2):336-343.
- SAINT-GERMAIN, M., BUDDLE, C., LARRIVÉE, M., MERCADO, A., MOTCHULA, T., REICHERT, E., . . . WEBB, A. (2007). Should biomass be considered more frequently as a currency in terrestrial arthropod community analyses? *Journal of Applied Ecology*, 44:330-339.
- SAMPLE, B., COOPER, R., GREER, R., & WHITMORE, R. (1993). Estimation of insect biomass by length and width. *American Midland Naturalist*, 129:234-240.
- SCHLEGEL, R. (1969). *Der Ziegenmelker (Caprimulgus europaeus)*. Lutherstadt Wittenberg, Germany: Die Neue Brem-Bücherei.
- SCHOENER, T. (1980). Length-weight regressions in tropical and temperate forest understory insects. *Annals of the Entomological Society of America*, 73:106-109.
- SIERRO, A., ARLETTAZ, R., NAEF-DAENZER, B., STREBEL, S., & ZBINDEN, N. (2001). Habitat use and foraging ecology of the Nightjar (*Caprimulgus europaeus*) in the Swiss Alps: towards a conservation scheme. *Biological Conservation*(98), 325-331.
- SMITH, A., HUDSON, M., DOWNES, C., & FRANCIS, C. (2015). Change Points in the Population Trends of Aerial-Insectivorous Birds in North America: Synchronized in Time across Species and Regions. *PLOS ONE*, 10(7):e01330768.
- TODD, L., POULIN, R., & BRIGHAM, R. (1998). Diet of common nighthawks (*Chordeiles minor*: Caprimulgidae) relative to prey abundance. *American Midland Naturalist*, 139(1):20-28.
- TRUXA, C., & FIEDLER, K. (2012). Attraction to light – from how far do moths (Lepidoptera) return to weak artificial sources of light? *European Journal of Entomology*(109), 77-84.
- VAN KLEUNEN, A., SIERDSEMA, H., NIJSSEN, M., LIPMAN, V., & GROENENDIJK, D. (2007). Jaar van de Nachtzwaluw 2007. SOVON-onderzoeksrapport 2007/10, SOVON Vogelonderzoek Nederland, Beek-Ubbergen.
- VAN NIEUKERKEN, E. J., KAILA, L., KITCHING, I. J., KRISTENSEN, N. P., LEES, D. C., MINET, J., . . . BAIXERAS, J. (2011). Order Lepidoptera Linnaeus, 1758. In: Zhang, Z.-Q. (Ed.) *Animal biodiversity: An outline of higher-level classification and survey of taxonomic richness*. Zootaxa.
- VERHEYEN, K., CEUNEN, K., & VANHELLEMONT, M. (2013). Wetenschappelijk bosvormingsexperiment Pijnven-Bosland.
- VERSTRAETEN, G., BAETEN, L., & VERHEYEN, K. (2011). Habitat preferences of European Nightjars *Caprimulgus europaeus* in forests on sandy soils. *Bird study*(58:2), 120-129.
- WATERINCKX, M., & ROELANDT, B. (2001). *De bosinventarisatie van het Vlaamse Gewest*. Ministerie van de Vlaamse Gemeenschap, Bos & Groen.
- YELA, J., & HOLYOAK, M. (1997). Effects of Moonlight and Meteorological Factors on Light and Bait Trap Catches of Noctuid Moths (Lepidoptera: Noctuidae). *Environmental Entomology*(97), 1283-1290.