Where to find the eggs and how to manage the breeding sites of the Brown Hairstreak (*Thecla betulae* (Linnaeus, 1758)) in Central Europe?

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Abstract. We investigated the oviposition preferences of the Brown Hairstreak (*Thecla betulae* (Linnaeus, 1758)) by characterising egg-deposition sites in an urban park in Münster (North Rhine-Westphalia, Northwestern Germany) in January and February 2002. Based on these preferences, we suggest methods for population surveys and the management of breeding sites of *T. betulae*. Covering a total area of 409 m², we systematically searched all *Prunus spinosa* host plant individuals for *T. betulae* eggs and recorded various host plant traits to characterise oviposition patterns. About 80% of all 320 clutches (348 eggs) were laid on the fork and 17% on the bud. The vast majority of the clutches (299 or 94%) was deposited at 50 to 170 cm above ground (median = 110 cm). Young plants or young suckers were strongly preferred. Oviposition height preferences and host plant use in *T. betulae* throughout Europe can best be explained by temperature. Oviposition heights and the size of selected host plants both tend to increase in warmer climates. Presumably, the preference for young plants and young suckers could to be determined by avoidance of inter-specific competition or a better plant quality, but this requires further evaluation. A "success-oriented" survey method for *T. betulae* should focus on the conspicuous white eggs that are best found on young plants or young suckers at 50 to 170 cm above ground in winter. We suggest that rotational scrub cutting is an appropriate tool for managing *T. betulae* sites.

Zusammenfassung. Die Eiablagepräferenzen des Nierenfleck-Zipfelfalters (*Thecla betulae* (Linnaeus, 1758)) wurden im Januar und Februar 2002 in einem Stadtpark in Münster (Nordrhein-Westfalen, Nordwestdeutschland) untersucht. Auf Grundlage der Ergebnisse werden Vorschläge zur Erfassung von *T. betulae*-Populationen und zum Management der Lebensräume gemacht. Alle potenziell geeigneten *Prunus spinosa*-Wirtspflanzen wurden systematisch nach Eiern abgesucht und verschiedene typische Wirtspflanzenparameter ermittelt. Auf einer untersuchten Gebüschfläche von 409 m² wurden insge-samt 320 Gelege mit 348 Eiern gefunden. Etwa 80% der Gelege befand sich an Astgabeln und 17% an Knospen. Die überwiegende Zahl der Gelege (299 bzw. 94%) war in Höhen zwischen 50 und 170 cm angeheftet. Jungpflanzen und Stockausschläge wurden stark präferiert. Die Eiablagehöhen und die Wirtspflanzennutzung werden innerhalb Europas vor allem durch die Temperatur bestimmt. Je wärmer das Klima desto höher über dem Boden erfolgt die Eibablage und umso stärker werden hochwüchsige Wirtspflanzenarten genutzt. Die Präferenz für Jungpflanzen und Stockausschläge scheint auf Vermeidung interspezifischer Konkurrenz oder eine bessere Wirtspflanzenqualität zurückzuführen zu sein. Die Erfassung von *T. betulae* erfolgt am Besten im Winter durch die Suche nach den auffälligen weißen Eiern an Jungpflanzen oder Stockausschlägen in Höhen zwischen 50 und 170 cm. Ein Auf-den-Stock-setzen der Gebüsche in jährlich wechselnden Abschnitten scheint eine geeignete Maßnahme zum Management der *T. betulae*-Habitate zu sein.

Key words. Blackthorn, Germany, host plant quality, inter-specific competition, oviposition preference, *Prunus spinosa*, survey method, urban park, young sucker

Introduction

Habitat quality is one of the main factors explaining the distribution of butterflies (Dennis & Eales 1997; Thomas et al. 2001; Fleishman et al. 2002; Fred & Brommer 2003; Anthes et al. 2003; WallisDeVries 2004). Due to their low mobility and proportionally long life time (Fartmann 2004), the immature stages often have more specific habitat requirements and are more susceptible to inadequate habitat management than the adults (Thomas 1991; Clarke et al. 1997; Thomas et al. 1998, 2001; Bourn & Thomas 2002; Fartmann 2004; Fartmann & Hermann, in press; García-Barros & Fartmann, submitted). Therefore the habitat requirements of preimaginal stages are often used to ascertain habitat quality.

Eggs or larvae are not only good indicators for habitat quality, they are also sometimes easier to detect than the adult stages and, conveniently, surveys are not weather dependent. In fact, Hermann (1999, in press) suggested that survey methods focusing on the immature rather than the adult stages are more adequate and more successful for approximately one quarter of the Central European species. This applies specifically to the hairstreaks, because their adults live mostly in the treetops and occur in low densities.

While extensive data on the distribution, status and ecology of the Brown Hairstreak (*Thecla betulae* (Linnaeus, 1758)) have been gathered for Britain (Thomas 1974, 1991; Thomas & Emmet 1989; Bourn & Warren 1998; Asher et al. 2001), the published knowledge of the species' ecology in continental Europe is still poor. Heddergott (1962) described a *Thecla betulae* outbreak in 1959 in Westphalia. A more detailed overview of the host plants and habitats in Southwest Germany was given by Ebert & Rennwald (1991). Koschuh et al. (2005) analysed the oviposition habitats in Southeast Austria and Stefanescu (2000) published data on the host plant species and the ant caterpillar associations in Northeast Spain.

We here supply information on the species' ecology in Central Europe. To do so, we will (i) describe the oviposition habitats, (ii) give hints for assessing the status and (iii) make recommendations for management.

Material and Methods

Study species. *Thecla betulae*, the Brown Hairstreak, has a wide distribution in the Nemoral zone of the Palaearctic (Thomas 1974). It reaches its distribution borders in southern England, Wales and Ireland to the west (Asher et al. 2001), in southern Scandinavia to the north and in the northern Mediterranean region to the south (Thomas 1974; Ebert & Rennwald 1991; Kudrna 2002).

The Brown Hairstreak is present in all German federal states, but the general distribution and the status are still poorly known. Recent egg surveys in the Saarland (Caspari pers. comm.) and the city of Münster (Leopold pers. comm.) revealed surprisingly wide distributions in regions that have previously been thought to be sparsely inhabited, suggesting that the species is more widespread than often assumed.

The flight period in Germany extends from early July to mid-October (Ebert & Rennwald 1991; Fartmann 2004). The eggs of *T. betulae* hibernate firmly attached to the bark of the host plants. Hatching of the larvae coincides with the leaf break of the host plant (Thomas 1974). The main host plant throughout Europe is *Prunus spinosa* (Blackthorn). First caterpillars usually appear in late April or early May (Heddergott 1962; Ebert & Rennwald 1991; own observation). All four larval instars consume only leaves. Adult *T. betulae* may predominantly feed on aphid honeydew secretion, but this

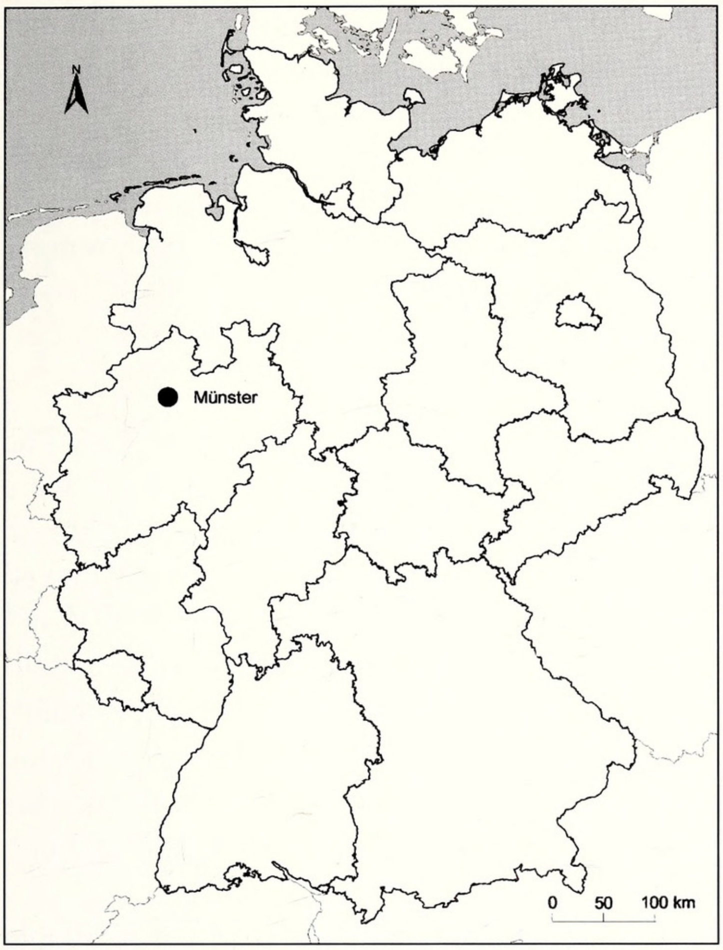

Fig. 1. Location of the study area in northwestern Germany.

is seldomly observed because of its inconspicuousness in the treetops (Thomas 1974). In addition, females regularly feed on plant nectar (Bourn & Warren 1998). The fecundity of females is linearly correlated with the longevity of the individual. The highest realised fecundity observed by Thomas (1974) was by a female that lived 39 days and laid 147 eggs.

T. betulae breeds over a wide array of habitats of the countryside, ranging from parks, gardens, hedges, woodland edges to other shrubby sites with *Prunus* species (Ebert & Rennwald 1991; Asher et al. 2001). The adults assemble at the beginning of the flight period on prominent "master" trees, mostly along wood edges in order to find mates (Thomas 1974; Asher et al. 2001).

Study area. The study area (hereafter called "Wienburg" park, 51°57'N/7°37'E) of about 26 ha is located in the northwest of the district of Münster, belonging to the northwestern part of the federal state of North Rhine-Westphalia (Northwest Germany) at an elevation of 55 m a.s.l. (Fig. 1). The climate is suboceanic (Müller-Wille 1981) with an annual precipitation of 757 mm and an average annual temperature of 9.2 °C (Deutscher Wetterdienst 2006). The Wienburg park was established in 1987 as a recreational area. It consists of a wet part with semi-natural ponds, swamp woods and abandoned wet grassland and a drier section with meadows, lawns, managed hedges, solitaire trees and groves. Before this, most parts of the study area were used as arable fields (Stadt Münster 1988, 2000). In the west and east the park is bordered by woodland.

Material and methods. The study area was selected because of its exceptionally high density of *T. betulae* eggs. In January and February 2002 all *Prunus spinosa* bushes and hedges of the study area were systematically checked for eggs. Two other *Prunus* species (*P. padus* and *P. ×fruticans*) occur in the study area, but they are rare and were not controlled. The survey was restricted to a section of 50 cm depth of the bushes and ranging from ground to 350 cm height. We searched for eggs until no more eggs were found on the plant, but individual *Prunus* plants were considered unoccupied if no egg was found within 10 min. To avoid duplicate counting, all eggs were marked with a strip. For each occupied Blackthorn we determined total height (cm), egg-laying height

above ground (cm) and the position of the clutch (bud, fork, stem, twig). The number of eggs was recorded for each clutch. For all surveyed bush groups – whether occupied or not – aspect (using a compass) and ground coverage (m²) were determined.
Statistical analysis was performed using SPSS 8.0 statistical package. To establish habitat preferences, we compared host plant traits between occupied and unoccupied *Prunus* individuals using a chi-square test. Because this test does not allow empty categories, frequencies were conservatively set to 1 in those cases.

Results

We found a total of 320 clutches of *T. betulae* with 348 eggs in an area of 409 m². The mean density was 0.8 clutches and 0.9 eggs per m² *Prunus spinosa* bushes. Eggs were laid singly (92%), in pairs (7%) or rarely in small batches of 3 eggs (1%). Oviposition occurred preferably into the fork (80%), followed by buds (17%). Stem and twig played a minor role in egg deposition (Fig. 2).
Both, the distribution of host plant and egg-deposition height were more or less bell-shaped, but the peak of the host plant height shows a clear shift towards higher values. The vast majority of clutches (299 or 94%) was deposited in heights between 50 and 170 cm above ground (median = 110 cm, range 15 to 350 cm, Fig. 3). Almost all clutches (285 or 90%) were found on *P. spinosa* plants with a height between 80 and 260 cm. The median plant height was 180 cm.
Eggs were found in almost all aspects (Tab. 1), but the orientation of the available host plants and that of the host plants used for oviposition differed significantly

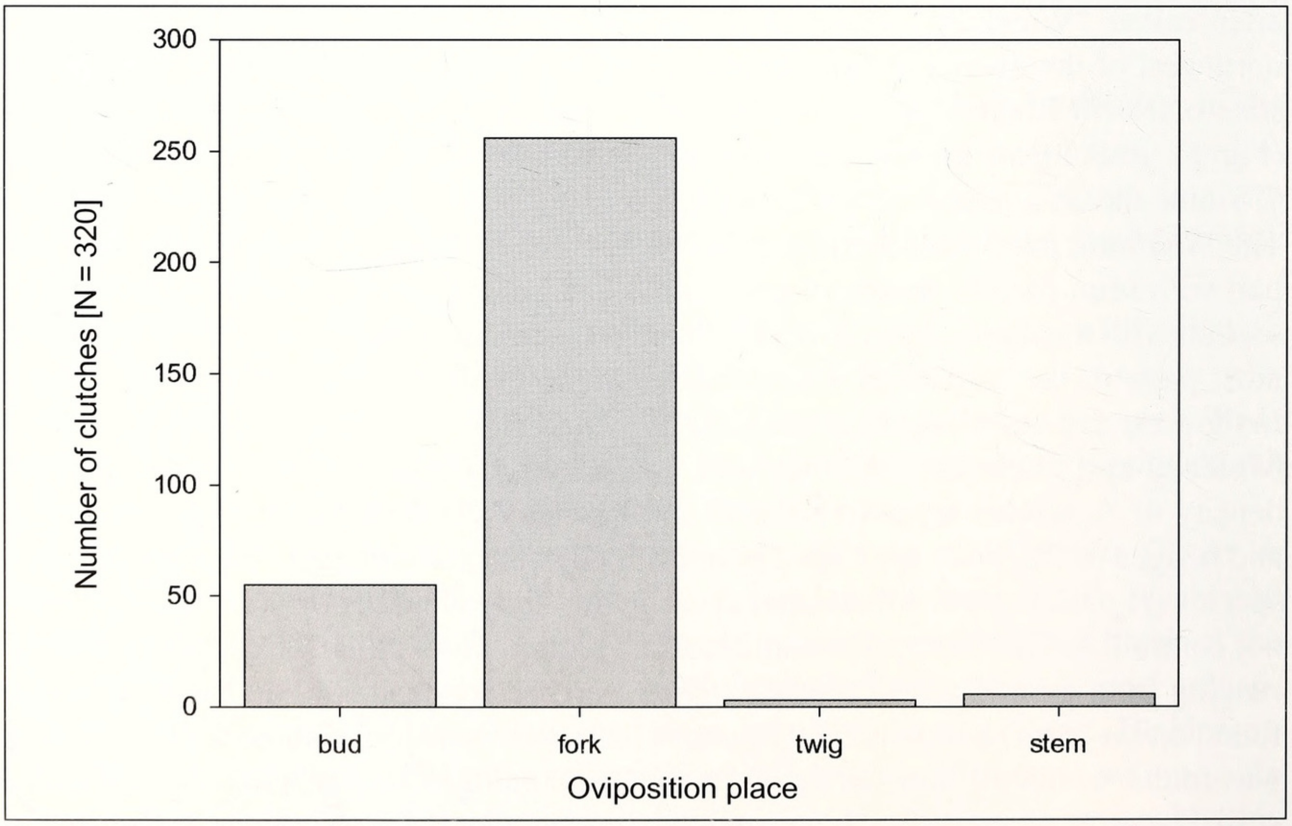

Fig. 2. Oviposition places of *Thecla betulae* on *Prunus spinosa*.

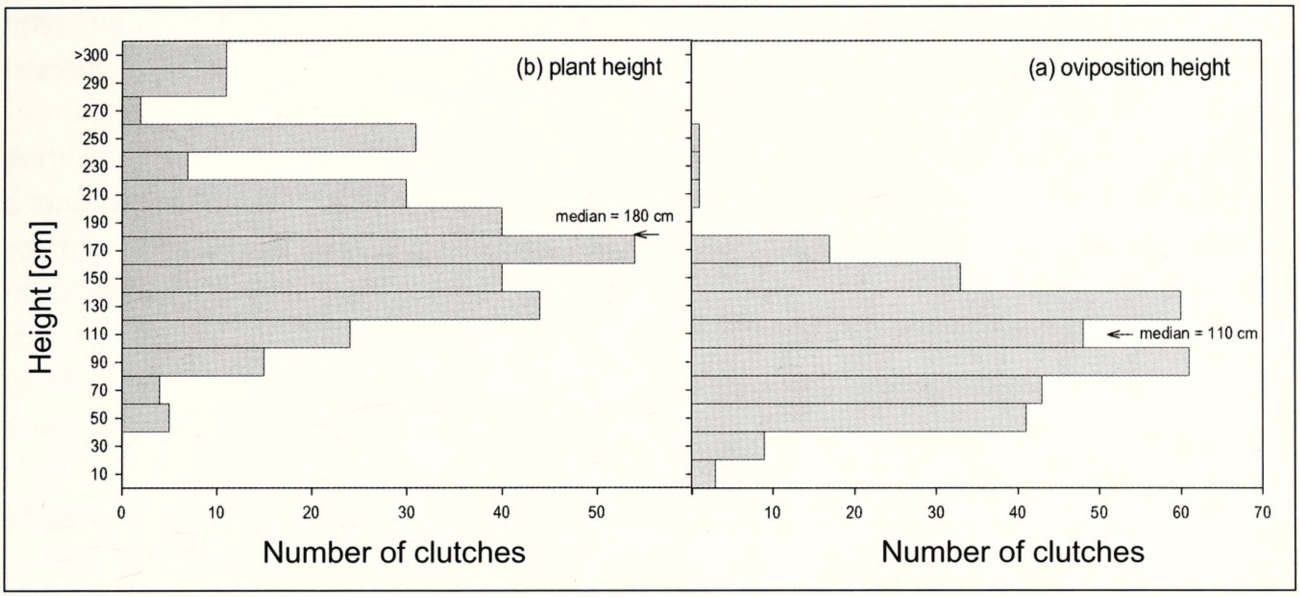

Fig. 3. Host plant and oviposition height of *Thecla betulae* (N = 318 clutches).

Tab. 1. Aspects of used and available host plants of *Thecla betulae*. $\chi^2 = 169.879$, df = 16, $P < 0.001$. + = overrepresented (absolute difference in proportion > 5%), – = underrepresented (absolute difference in proportion > 5%), – – = strongly underrepresented (absolute difference in proportion > 10%).

aspect	used host plants		available host plants		
	no. of batches	proportion (%)	area (m²)	proportion (%)	
N	0	0.0	14.3	3.5	.
NNE	9	2.8	6.5	1.6	.
NE	5	1.6	6.3	1.5	.
ENE	0	0.0	7	1.7	.
E	24	7.5	34.3	8.4	.
ESE	16	5.0	13.5	3.3	.
SE	53	16.5	42	10.3	+
SSE	47	14.6	30.5	7.5	+
S	32	10.0	28.3	6.9	.
SSW	8	2.5	6	1.5	.
SW	13	4.1	17.1	4.2	.
WSW	34	10.6	44.5	10.9	
W	16	5.0	79.9	19.5	– –
WNW	5	1.6	28.8	7	–
NW	33	10.3	21	5.1	+
NNW	4	1.3	20.5	5	.
–	22	6.9	8.8	2.1	.
Total	321	100	409	100	

($\chi^2 = 169.879$, df = 16, $P < 0.001$). There is no clear trend/preference for the main aspects N, E, S and W, but bushes exposed to SE, SSE and NW were used disproportionally often for oviposition, while W and WNW aspects were underrepresented.
It was striking that searching for the first egg on young Blackthorn shoots seldom took longer than one or two minutes, while many hours of searching in old bushes produced only a few eggs. The proportion of young, not flowering bushes and suckers in the study area is below 20% of all *P. spinosa* individuals. But far more than 50% of all eggs were found on these plants.

Discussion

Oviposition preferences. The eggs of *Thecla betulae* were usually laid singly on forks of *Prunus spinosa* at a height of less than 170 cm above ground. Young plants or suckers were strongly favoured.
The overall clutch sizes and the positions of the eggs on the plant documented here corroborate the findings of previous studies (Thomas 1974; Henriksen & Kreutzer 1982; Bourn & Warren 1998; Asher et al. 2001; Koschuh et al. 2005). The few differences between studies concerning oviposition height, host plant use and sun exposition seem to be related to the variation in climate conditions across Europe. The warmer the climate the more different host plant species are used, the higher the clutches are laid and the more eggs are found on shadier sites: The main host plant in Scandinavia as well as in Britain is *P. spinosa* (Thomas 1974; Henriksen & Kreutzer 1982). In most Central European regions and in most of the years the major host plant is also *P. spinosa* (SBN 1987; Ebert & Rennwald 1991; Weidemann 1995; Hermann pers. comm.). However, other *Prunus* species like *P. avium*, *P. domestica*, *P. insititia* or *P. padus* are also mentioned as a host plant (Ebert & Rennwald 1991; Koschuh et al. 2005). Heddergott (1962) described the intensive use of *P. domestica* by *Thecla betulae* in dry summers in Westphalia, whereas the normal host plant in this region is *P. spinosa*. Koschuh et al. (2005) found *P. insititia* as the main host plant in Southeast Austria. Stefanescu (2000) also mentioned a wider range of *Prunus* host plant species from Northeast Spain.
In Scandinavia only the smallest bushes were used for egg-laying (Henriksen & Kreutzer 1982). In Britain most eggs were found below 200 cm above ground with a peak at around 50 cm (Thomas 1974). In the own study area in Northern Germany the median oviposition height was 110 cm. Koschuh et al. (2005) found a preferred oviposition height between 100 and 200 cm in Southeast Austria. Comparable shifts in oviposition habitats along climatic gradients throughout Europe are well known from other butterfly species; maybe one of the best studied examples is *Maculinea arion* (Thomas et al. 1998).
While references from Britain stated a preference for sun exposed egg-laying sites (Thomas 1974; Bourn & Warren 1998; Asher et al. 2001), Koschuh et al. (2005) described the oviposition habitats in Austria as sunny to half shady. The own data show no clear results because aspect features are superposed by other parameters like shoot

age. An overall impression is that host plants should not grow in particularly shady conditions. However, after very hot summers as 2003 or in generally warmer regions of Central Europe as Southwest Germany many or even the majority of the eggs are laid on shaded parts of the host plant (Caspari pers. comm.; Hermann pers. comm.).

The general preference for young plants, young projecting growth or young suckers is well documented by Thomas (1974). He showed that shoots younger than 6 years but older than 1 year are preferred for egg-laying. Most eggs were found on 4 years old shoots. Only *P. spinosa* plants older than 6 years are able to produce flowers. Epicormic growth can start flowering two years after coppicing (Hermann pers. comm.). The preference for young shoots in the study area would have been far more striking if the surface had also been taken into account. The bark surface area of an old bush may present the 100-fold of that of a young plant (Thomas 1974). In contrast to this Ebert & Rennwald (1991) state that most larvae and eggs were found on older specimen of *P. spinosa* and that this applies to Baden-Württemberg in general. According to our study and further own observations, females use old *P. spinosa* plants for oviposition if they have no other choice. However, if young suckers a few years after coppicing are present, females will clearly prefer these plant individuals. Egg densities on old shoots will usually never reach the values of the young shoots. Hermann (pers. comm.) also found a preference for young growth in Baden-Württemberg.

But why are young plants or young suckers preferred? Young plants are comparatively small and they do not flower. Older plants are tall growing, but they usually have also twigs near the ground and they are producing flowers. Microclimatic features could not explain the preference for young plants or suckers because the old *P. spinosa* bushes also provide many potential egg-laying places with leaf buds in the favoured layer near ground. Young plants could invest all their energy into leaf growth and development, whereas older plants need energy for flower production. Therefore, the total amount of leaves and the content of water and nutrients in the leaves can be different between these two groups. Enough food is essential for the survival of the larvae (Fartmann & Hermann, in press; García-Barros & Fartmann, submitted). However, food shortage due to intra-specific competition is unlikely a problem for *Thecla betulae*. Eggs are usually deposited singly, and in rather low densities per plant such that competition between caterpillars should hardly occur. In consequence, defoliation of a host plant individual has thus far only been documented once, in an extraordinarily warm year (Heddergott 1962).

More likely, inter-specific competition or food plant quality could act as the key for the understanding of the preference for young shoots. There are many *Prunus* feeding and egg-clustering moth species (e.g. *Yponomeuta* spp.), that are able to defoliate *Prunus* bushes during the larval period of *Thecla betulae*. Due to the high demand of food for their offspring they seem to live predominantly on older plants (Caspari pers. comm.). Therefore, egg-laying on young shoots by *Thecla betulae* could be interpreted as avoidance of interspecific competition.

In addition, another reason for the preference for young shoots could be the host plant quality. Butterflies that feed on nutrient-rich parts of a plant often have a faster larval development and the survival rates of the butterflies are higher (see review by Fartmann & Hermann, in press). Both explanations require further evaluation.

Thomas (1974) found that almost all observations of *T. betulae* are from wood edges or hedges near woods. The egg density was significantly higher within a distance of 250 m from woods than further away. Fartmann (2004) showed in a study of 53 butterfly transects in calcareous grasslands in northern Germany, that *T. betulae* was more steady in sites adjacent to woods. Thomas (1974) explains this with the importance of prominent trees ('master trees') on wood edges for congregations of adults. Here they feed on honeydew and search for mates (Thomas 1974; Asher et al. 2001). In Britain, Ash trees (*Fraxinus excelsior*) are preferred probably because honeydew producing aphids are abundant on them (Asher et al. 2001).

Although the host plant is abundant, large areas of a *T. betulae* breeding site are often characterised by low egg densities, only certain areas have high egg numbers (Thomas 1974). Comparable density data from Europe are still missing, but based on our own field experience the Wienburg park is certainly a high-density area with a mean density of 0.8 clutches and 0.9 eggs per m^2 of *Prunus* bushes. Reasons could be the high abundance of the preferred young shoots due to the rotational cutting of the hedges and probably the adjacent woods with their feeding and congregation places for the adults.

How to survey *Thecla betulae*? Our knowledge on the status of *Thecla betulae* in most of its range is scarce because of the cryptic way of living of the butterflies and their low densities. The most effective method of surveying the species is searching for the conspicuous white eggs in winter (i.e. between November and February) (Thomas 1974; Bourn & Warren 1998; Hermann 1999). Therefore you need to know were to search. Based on our own results, searching will be most successful on young plants or young suckers in a height between 50 and 170 cm. Old and tall flowering bushes with lichens and algae are hardly suitable. Especially for presence/absence studies this searching scheme will be useful. For counting total egg number in a distinct area it could be helpful to mark every spotted egg. In our study the recording accuracy decreased with recording duration. After a lengthy time of extensive searching the concentration of the recorders usually fell. Continuing the survey the next day at the same place often revealed new and previously overlooked eggs. Therefore it would be good to stop searching when concentrating becomes difficult and to continue when recovered.

Management. In most German federal states, *Thecla betulae* is a species of low conservation concern (see summary of red list categories in Reinhardt & Settele 1999). Sometimes *T. betulae* and more specialised and more highly endangered species such as *Eriogaster catax*, *Iphiclides podalirius* or *Satyrium acaciae* share the same host plant. In these cases or where other conservation aims are more important, conservation efforts cannot focus on *T. betulae*. Nevertheless, *T. betulae* breeding sites without species of high conservation interest – like our study area and other urban parks – could be managed for the Brown Hairstreak. On the one hand, cutting and trimming of hedges is one of the most important mortality factors in *T. betulae*. On the other hand, optimal habitats are created by this management. Thomas (1974) ascertained egg losses between 50 and 100% due to cutting. Most eggs are deposited on the younger projecting growth rather than deep within the hedge and therefore they are affected by cutting. To reduce the heavy egg losses and in return to assure the presence of many *Prunus* shoots in the preferred age (2–6 years), rotational scrub cutting is an appropriate tool (Thomas 1974). After Thomas (1974) a quarter of the breeding site should be trimmed every fourth year. Observations from Oates (in Bourn & Warren 1998) showed that *T. betulae* responded well to Blackthorn coppicing, favouring plants 3–5 years after the cut (Oates in Bourn & Warren 1998).

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