Emergence patterns of *Ips typographus* and *Medetera* spp. after overwintering in killed spruce trees

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Abstract

Ips typographus (Coleoptera: Curculionidae, Scolytinae) is a pest species that mainly attacks Norway spruce (*Picea abies* L. Karst.) and can kill large volumes of spruce trees during outbreaks, leading to economic losses of great magnitude. A common practice to manage attacks is to remove recently killed trees and thereby remove the beetles. Spruce bark beetles are limited by natural enemies that can reduce bark beetle emergence by more than 83%.

The aim of this study was to investigate the emergence progression of *Medetera* spp. and bark beetles *I. typographus* in Uppsala Sweden together with recorded thermal sums of different sun exposures. This was done in an outdoor experiment where logs from bark beetle killed spruce trees were placed in emergence boxes with different sun exposure.

I report a lag of roughly 7 days between ≥ 50% cumulative emerged *I. typographus* and *M. signaticornis*. The difference in number of days until ≥ 50% had emerged was significant when comparing the two species. There was also a significant effect of treatment on both *M. signaticornis* and *I. typographus* ($p =< .001$, $\eta^2 = 0.341$). Three species of *Medetera* were identified and differences in emergence patterns were observed with *M. signaticornis* being the earliest (and most common species), *M. pinicola* next earliest and *M. ambigua* the latest emerging species. Thermal sums at 50% cumulative emerged *Medetera* spp. and *I. typographus* differed significantly.

This study reveals for the first time how *I. typographus* and *Medetera* spp. respond to accumulating thermal sums after overwintering. Results from this study gives an insight into how attacked trees should be managed to reduce the risk of removing natural enemies from the forest.

Keywords: Ips typographus, *Medetera*, *M. signaticornis, M. pinicola* and *M. ambigua,* emergence patterns

1. Introduction

1.1 Background

The European spruce bark beetle *Ips typographus* (Coleoptera: Curculionidae, Scolytinae) is a pest species that mainly attacks Norway spruce (*Picea abies* L. Karst.) in Europe. Under outbreak conditions the beetle can kill large volumes of spruce trees and in Sweden the latest outbreak from 2018 has killed more trees than ever before (Schroeder & Kärvemo 2022). For the forest owners this may lead to economic losses of great magnitude (Kärvemo & Schroeder 2010). Factors affecting *I. typographus* outbreaks are for example storms and drought (Wermelinger 2004; Schelhaas et al. 2003). Storms can lead to an increase in wind felled trees, thereby creating available breeding material in large amounts, leading to an increase in spruce bark beetle populations (Hedgren & Schroeder 2004). This in turn could be one explanation to why the amount of available storm felled trees one year is correlated to more timber loss the next (Marini et al. 2017). However, even in the absence of storms, factors associated with climate change are also affecting outbreaks of spruce bark beetles and can cause timber loss. Like all insects, bark beetles are ectothermic and the development rate from egg to adult as well as flight activity of adult beetles depend on the temperature (Wermelinger 2004) and are thereby also sensitive to climate change (Bentz et al. 2019).

An increase in summer temperature combined with less rainfall during the previous year can lead to outbreaks and forest damage on Norway spruce (Marini et al. 2017). The current outbreak of *I. typographus* in Europe was probably triggered by extreme drought together with high temperatures in 2018, which lowered the resistance of the trees and led to multiple flight and attack periods during the summer (Schroeder & Kärvemo 2022). Although it is clear that *I. typographus* outbreaks are triggered by the supply of susceptible breeding material (e.g., wind-felled or drought stressed trees) other factors can affect the mortality of the immature stages under bark. One of the most important factors are natural enemies, among which long-legged flies of the genus *Medetera* (Dolichopodidae), which are the focus of this report, are among the most common.

1.1.1 Spruce bark beetle

Spruce bark beetles start their flight in the spring when the temperature rises and search for suitable host trees to mate and breed in (Öhrn 2012). The male bark beetle bores into the tree and creates a nuptial chamber in the bark and starts to attract conspecifics of both sexes by releasing an aggregation pheromone (Christiansen & Bakke 1988). The spruce bark beetle is a polygamous species and males usually mate with two or three females, which each creates an egg gallery in the phloem in which up to 80 eggs are laid (Wermelinger 2004; Hedgren & Schroeder 2004). The length of the gallery is proportional to how many eggs the females have laid in it (Anderbrant 1990). The development time from egg to adult is four to six weeks, depending on temperature, after which the callow adults need to feed in the bark to mature (Annila 1969 and references therein). In Sweden, *I. typographus* are mostly univoltine and overwinter either in the ground or in the trees where they have developed. After overwintering they emerge in spring after reaching an accumulated temperature sum (see below) when the temperature is high enough for flight.

Certain temperatures are needed to initiate flight and Annila (1969) reports that beetles that hibernated in soil required temperatures over 20 ˚C to fly. Optimal flight temperatures are between 22 to 26 ˚C (Wermelinger 2004). An increase in temperature up to certain levels can decrease the development time from egg to imago (Öhrn 2012) and lead to a faster population growth (Wermelinger & Seifert 1999). However, an increase in temperature does not always lead to more optimal conditions for the beetles. For example, Wermelinger and Seifert (1999) found that temperatures above 30 ˚C can lead to a deterioration of population growth.

Temperature also has an impact on voltinism, which is the number of generations produced in a year. More generations per year will increase the risk of damage by bark beetles (Nordkvist 2023). This differs between central Europe where up to two or three generations in one year are common (Wermelinger et al. 2012) compared to northern Europe, where univoltine reproduction is most frequent (Anderbrant 1989; Fritscher & Schroeder 2022). This indicates that when temperatures in northern Europe increase due to climate change, multivoltinism is more likely to occur (Jönsson et al. 2007). Furthermore, recent studies from southern Sweden concluded that initiation of second generation broods are occurring frequently (Öhrn et al. 2014). The same was shown for sister broods which could be the result of an increase in temperature (Öhrn et al. 2014).

1.1.2 Natural enemies

During all stages of development, bark beetles are attacked by several predators and parasitoids. Some species, *Thanasimus* spp. for example, have been studied more closely in the laboratory and their predation can reduce the productivity of *I. typographus* significantly (Weslien 1994). Field experiments in which the whole complex of bark beetle enemies have been excluded by fine-mesh nets show that the enemies can reduce *I. typographus* emergence by 40-80% (Weslien & Regnander 1992; Weslien 1992; Weslien & Schroeder 1999; Schroeder 2007b), depending on the abundance and species composition. Weslien (1992) reports that natural enemies of spruce bark beetles can reduce bark beetle emergence by up to 83%. This was found in an experiment where spruce bark beetle infested logs were left outside to be colonized by natural enemies for different periods of time. The longer the logs were exposed the higher number of natural enemies and lower number of *I. typographus* were found. In that experiment predatory long-legged flies of the genus *Medetera* and parasitic wasps were the most common enemies and accounted for much of the reduction in *I. typographus* production (Weslien 1992).

Medetera spp.

One of the most important predators on *I. typographus* is long-legged flies of the genus *Medetera* which belongs to the family Dolichopodiadae. Species from the *Medetera* genus can be found across the globe (Pollet et al. 2011) and they are said to be very difficult to identify among the Dolichopodidae flies (Sousa 2019). There are more than 250 described species of the *Medetera* genus of which some are specialized on bark beetles (Bickel 1985).

Larvae of *Medetera* has been estimated to consume roughly five *I. typographus* each (Weslien & Regnander 1992 and references therein). The larvae of *Medetera* spp. that feed on *I. typographus* overwinter under the bark of spruce trees in Sweden (Weslien 1992, Hedgren & Schroeder 2004). Wermlinger (2004) reports that peak flight of *Medetera* in Switzerland occurs one week after peak flight of *I. typographus*. There are no studies on flight patterns of *Medetera* in Sweden but Weslien (1992) did not record any *Medetera* emerging from exposed logs one week after *I. typographus* attack. There are several *Medetera* species that live in the gallery systems of *I. typographus,* but it seems that *M. signaticornis* is the most abundant (Weslien 1992, Hedgren & Schroeder 2004).

In conclusion, long-legged flies are important enemies of *I. typographus* and little is known about the difference in flight patterns of the different *Medetera* species in relation to *I. typographus* flight and attack times. It is important to get a better understanding of the relationship between the emergence of *I. typographus* and *Medetera* spp. because this may help to decrease the risk that control measures against *I. typographus* does not cause substantially greater mortality of *Medetera* spp. than of *I. typographus*.

Thermal sums

The rate of insect development is largely dependent on how long it has been warmer than a certain temperature threshold and how high these temperatures are. When studying insect development, thermal sums are a useful measure that can be applied to study flight periods, time of development and emergence. Thermal sums are the sum of the mean temperature over a threshold, most commonly +5 ˚C, and can be calculated in the lab (Annila 1969) and in the field (Öhrn et al. 2014). This gives a measurement of degree-days (dd). Different species of insects require different thermal sums to initiate spring flight. For *I. typographus* to begin its flight period a certain thermal sum must be reached (Dolezal & Sehnal 2007). Öhrn et al. (2014) found that *I. typographus* in southern Sweden required accumulated average thermal sums of 47 ± 24 dd (>5°C) to initiate spring flight. For *Medetera* spp. there are no previous studies on the thermal sum required before spring emergence starts.

1.2. Aim of study

The aim of the study was to investigate the emergence patterns of *Medetera* and *I. typographus* after overwintering, together with recorded thermal sums during their emergence. The results could be applied to how spruce bark beetle attacked trees should be managed and give an insight into how sun exposure influences the emergence of the two species.

I addressed the following questions: Are there differences in emergence patterns between different *Medetera* species? Are there differences in emergence patterns between *Ips typographus* and *Medetera* spp.? If so, can this difference be quantified in days and or thermal sums?

2. Materials and methods

2.1 Study site

Two bark beetle killed spruces attacked 2021 from Korpboström (59.769708, 17.9805) east of Uppsala Sweden were felled in and each tree was cut into ten logs on 14th of April (tree A) and 28th of April (tree B) 2022. The two trees were picked among trees that were judged to have a high density of *Medetera* larvae based on earlier experience and on the following criteria: without signs of woodpecker foraging, a diameter at breast height of at least 25 cm and with detected *Medetera* larvae in the bark at breast height. The logs of tree A were cut from a height of 1.5m to 6m with 0.5m intervals and the logs from tree B from a height of 5m to 9.5m with 0.5m intervals. The logs were stored in a cooling room at +5 ˚C until the 19 May, when six logs from each tree (Table 1) were randomly allotted and placed in emergence traps outdoors.

Table 1. The length and diameter of the logs with corresponding ID.

ID	Length (cm)	Diameter (cm)
B5	54	26
B9	52	22
A10	54	25
A9	53	24
B4	54	25
B7	53	25
A4	52	29
B1	54	26
A5	53	26
A1	53	30
B2	52	26
A7	52	26

2.1.1 Exposures

Trees attacked by *I. typographus* can vary in the degree of sun-exposure and therefore it can be anticipated that emergence starts earlier from sun-exposed trees. This could mean that the emergence patterns differ between trees in forest stands compared to clear cut edges. For this experiment three treatments with different exposure were include in the study: sun, intermediate and shadow. The 12 emergence traps were placed in the three different sun exposures on the 19th of May

2022 and the first recorded emergences on the 20th of May 2022. From the 20 logs, four logs were randomized per treatment with the condition that two logs with consecutive height were not allowed from the same tree (Table 2).

Table 2. Different heights above ground of the logs from the two trees denoted as A and B for the different treatments.

Treatments	Heights tree A (m)	Heights tree A (m)	Heights tree B (m)	Heights tree B (m)
Sun	4.5	5.5	8	9
Intermediate	3	6	5,5	6.5
Shadow	1.5	3.5	5	7

2.1.2 Emergence traps

The aim was to trap the emerging insects from the logs. The emergence traps were made of plywood boxes with a transparent plastic tube protruding from the lid of the box (Figure 1). A white plastic bottle was fastened on the tube. The lid of the bottle was cut open to fit a second tube to go over the tube connected to the lid of the box to prevent the emerging insects from ascending back into the wooden box. The logs were placed on two wooden planks inside the box to prevent the logs from lying directly on the bottom of the traps so that bark beetles and *Medetera* were able to bore out of the logs more freely.

Between the log and the inside of the plastic tube, a small wooden stick was placed so that insects could climb into the tube. Before the start of the experiment, the set-up was tested to ensure that the insects successfully reached the bottle. Tiny Tag temperature loggers were placed inside the traps, recording temperature every 30 minutes. The lid of the box was sealed tight with duct tape. To protect the inside of the box from rain, a plastic cover was placed around each box except for the plastic bottle.

The bottles were emptied during weekdays and the insects frozen in -18°C. Thereafter, the content of the bottles was sorted and counted with focus on *I. typographus* and long- legged flies of the genus *Medetera*. At the end of the experiment (5th of July 2022) the content of the emergence boxes was thoroughly examined and any remaining *Medetera*, *I. typographus* and Chalchid wasps were documented. *Medetera* specimens were determined to species by Marc Pollet.

Figure 1. Construction of trapping device mounted on hatching box.

2.2 Thermal sums

When calculating the thermal sums for emergence of *Medetera* and *I. typographus* 5˚C was used as the lower developmental threshold. This threshold for *I. typographus* was used by Annila (1969) and has been used in studies since (Jönsson et al. 2011; Öhrn et al. 2014). The thermal sums were calculated by adding the daily mean temperatures above the threshold 5˚C.

2.3 Comparison of emergence at 50% between species

The number of days until ≥ 50% cumulative emergence was reached was tested between *Medetera signaticornis* and *I. typographus* by comparing the emergence from the same logs in a pairwise t-test. Analyses were run on *M. signaticornis* since it was the most abundant species. A two-way analysis of variance was used to analyze the combined effect of treatment and species (*I. typographus* or *M. signaticornis*) on the number of days until ≥ 50% cumulative emergence was reached for each species. Analyses were performed in JASP Team (2023). JASP (Version 0.17.1) [Computer software]. One log was removed from the analyses since only three specimens of *Medetera* spp. emerged of which only one was *M. signaticornis*.

2.4 Comparison of thermal sums for *Medetera* and *I. typographus* between treatments

Interpolation of the data was done using piecewise linear function in Python. The thermal sums at different percentages of cumulative *Medetera* spp. and *I. typographus* (25, 50, and 75) were acquired from the interpolated data and tested against each other with one-way analysis of variance in JASP. Welch homogeneity corrections was used since variances of the groups differed. Also, here the log with only three specimens of emerged *Medetera* spp. was removed before statistical analyses were run.

3. Results

3.1 Emergence of *Medetera* and *I. typographus*

In total more than 7000 *I. typographus* emerged with quite small differences between the three treatments (Figure 2). Almost 500 *Medetera* spp. emerged with larger differences between treatments (Figure 3).

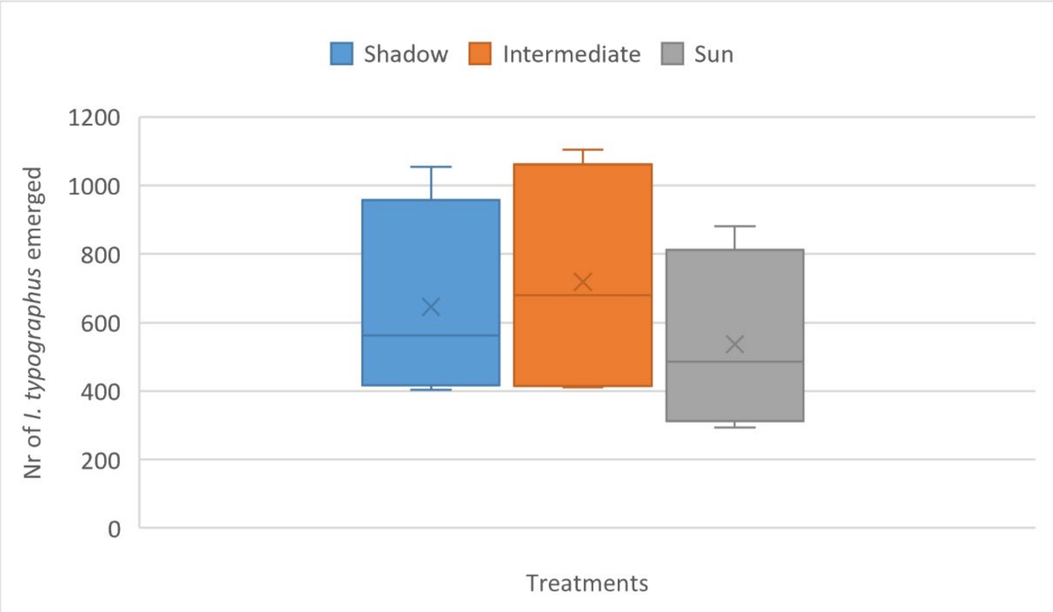

Figure 2. The number of emerged *I. typographus* from each treatment. The band represents the median, the whiskers show the min and max value. Box shows the upper and lower quartiles. Each treatment included four logs from bark beetle killed trees. Data recorded from 20th of May 2022 until 5th of July 2022.

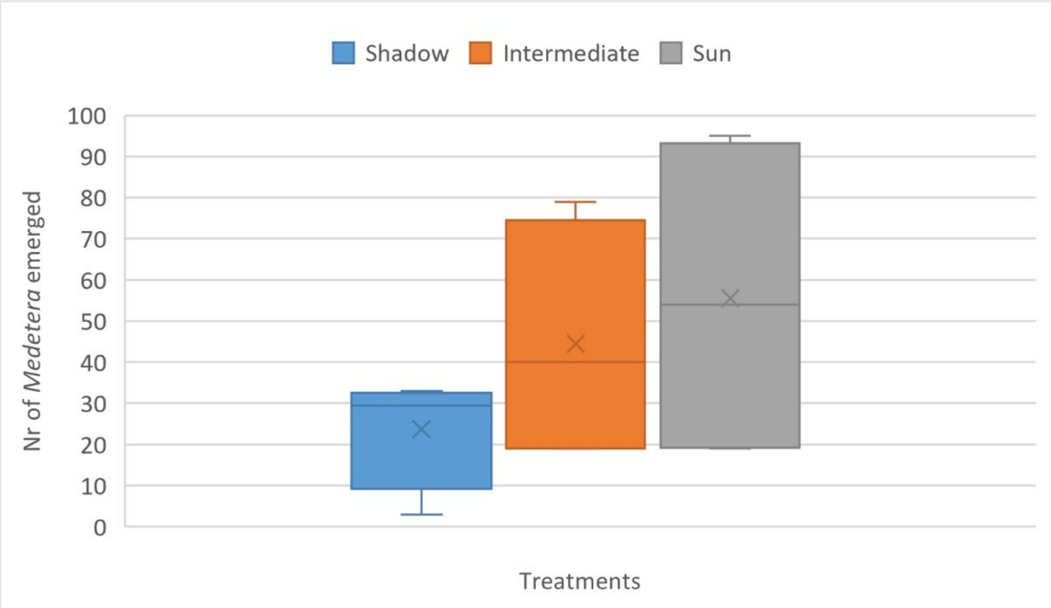

Figure 3. The number of emerged *Medetera* spp. from each treatment. The band represents the median, the whiskers show the min and max value. Box shows the upper and lower quartiles. Each treatment included four logs from bark beetle killed trees. Data recorded from 20th of May 2022 until 5th of July 2022.

Medetera species

Three different *Medetera* species emerged from the 20th of May until 5th of July 2022; 432 individuals *of Medetera signaticornis (*Loew 1857), 39 individuals of *Medetera pinicola (*Kowarz 1877) and 20 individuals of *Medetera ambigua* (Zetterstedt 1843) (Table 3). All three *Medetera* species were found on both trees and the ratio between them per species were somewhat similar comparing the two trees, except for *M. Ambigua* (Table 4). In total 495 *Medetera* emerged of which four individuals were unidentified. All three *Medetera* species were found on both trees (Table 3).

Table 3. Number of emerged individuals from M. signaticornis, M. pinicola, M. ambigua and I. typographus from all logs with corresponding heights and the ID of the logs. A and B are the two trees where A was cut on 14th and B cut on the 28th of April 2022. Data recorded from 20th of May 2022 until the 5th of July 2022. In total 491 identified Medetera.

ID	Logs A, B height (m)	*Signaticornis*	*Pinicola*	*Ambigua*	*I. typographus*
A7	4.5	80	5	3	369
A9	5.5	88	3	4	293
A4	3	67	2	9	424
A10	6	54	4	3	411
A1	1.5	16	11	0	403
A5	3.5	25	6	0	460
B7	8	19	0	0	880
B9	9	18	1	0	603
B2	5.5	15	3	1	1105
B4	6.5	17	2	0	934

B1	5	1	2	0	1054
B5	7	32	0	0	664

Table 4. Total amount of reared individuals of Medetera (M. signaticornis, M. pinicola, M. ambigua) and I. typographus for the two trees A and B. Data collected from the 20th of May 2022 until the 5th of July 2022.

Tree	*M. signaticornis*	*Pinicola*	*Ambigua*	*I. typographus*
A	330	31	19	2360
B	102	8	1	5240

At termination of experiment

At the termination of the experiment the number of *I. typographus* and *Medetera* spp. left in the boxes were counted, which indicated 99,5% and 98, 8 % emergence of *I. typographus* and *Medetera* spp. respectively.

3.1.1 Emergence patterns

The mean number of days from the initiation of the experiment (20th of May 2022) until ≥50% mean cumulative percentage *I. typographus* had emerged for treatments sun, intermediate and shadow were 13, 11 and 18 respectively (Figure 4). The same numbers for *M. signaticornis* were 21, 19 and 25 respectively (Figure 5).

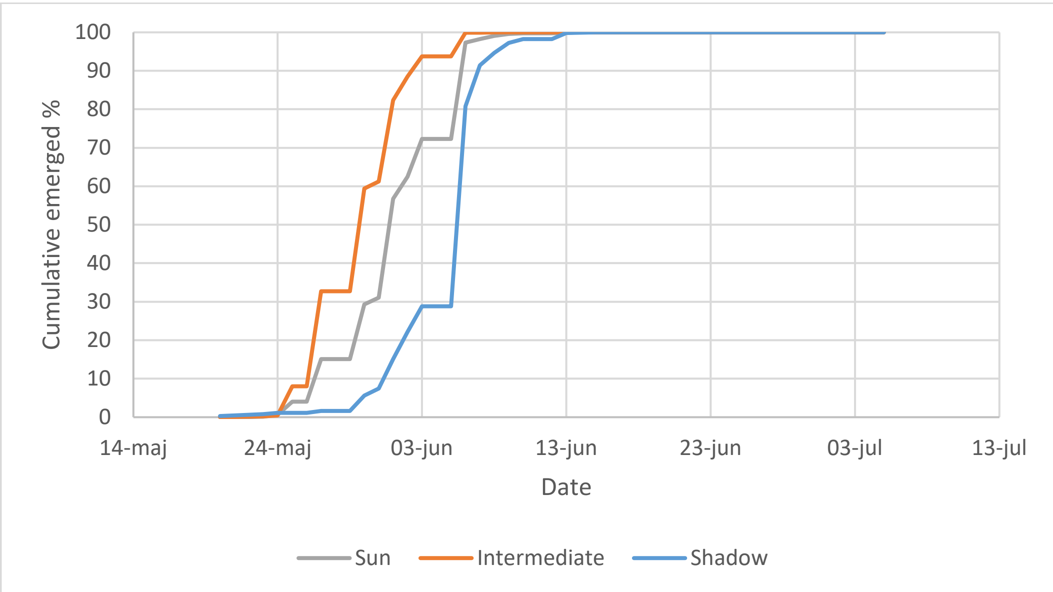

Figure 4. The mean cumulative percentage of emerged *I. typographus* per treatment. Data recorded from 20th of May 2022 until 5th of July 2022.

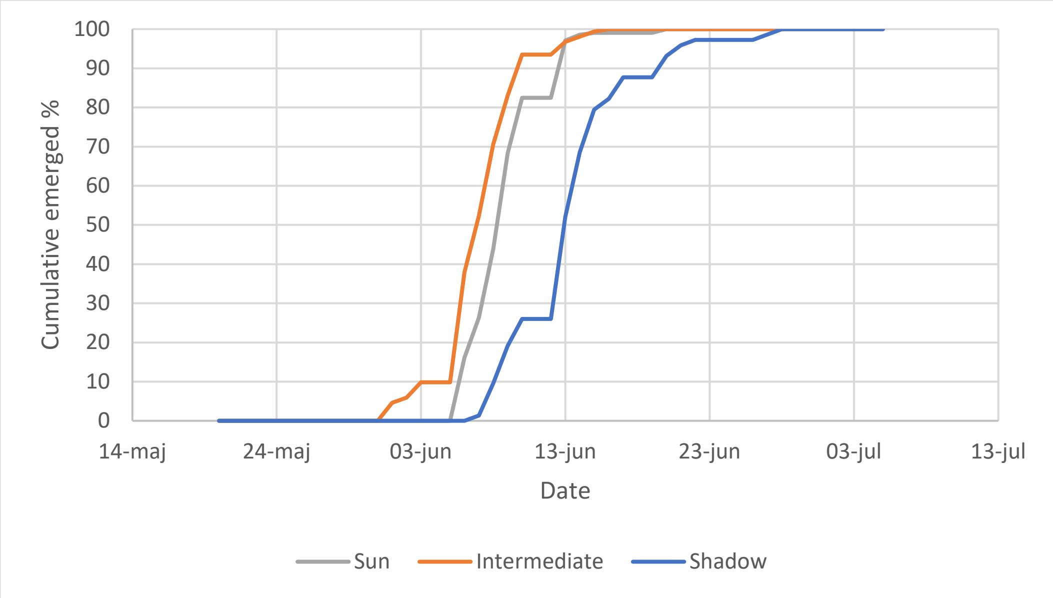

Figure 5. The mean cumulative percentage of emerged *M. signaticornis* from different sun exposures (sun, intermediate and shadow). Data from 11 logs recorded in Sweden from 20th of May 2022 until 5th of July 2022.

The mean thermal sum when mean ≥50% cumulative percentages was reached for *I. typographus* was at thermal sum 115.7 and 213.3 for *M. signaticornis* (Figure 6).

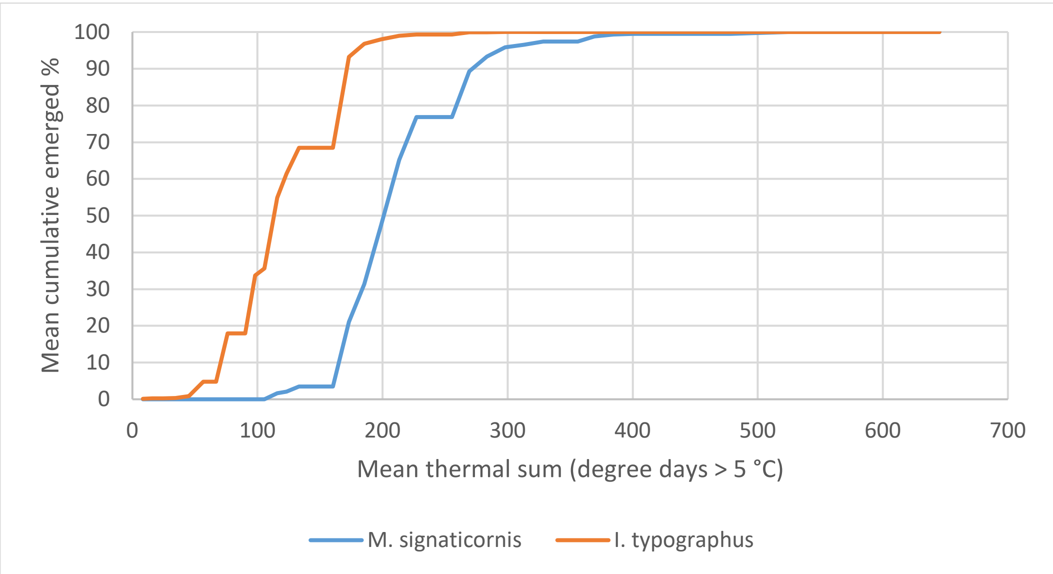

Figure 6. Mean cumulative emerged *M. signaticornis* and *I. typographus* over mean thermal sums shown as degree days > 5 °C. Data from 11 bark beetle infested logs recorded in Sweden from 20th of May 2022 until 5th of July 2022.

The mean ≥50% cumulative percentages were reached for *M. signaticornis, M. pinicola* and *M. ambigua* 21, 33 and 46 days respectively (Figure 7).

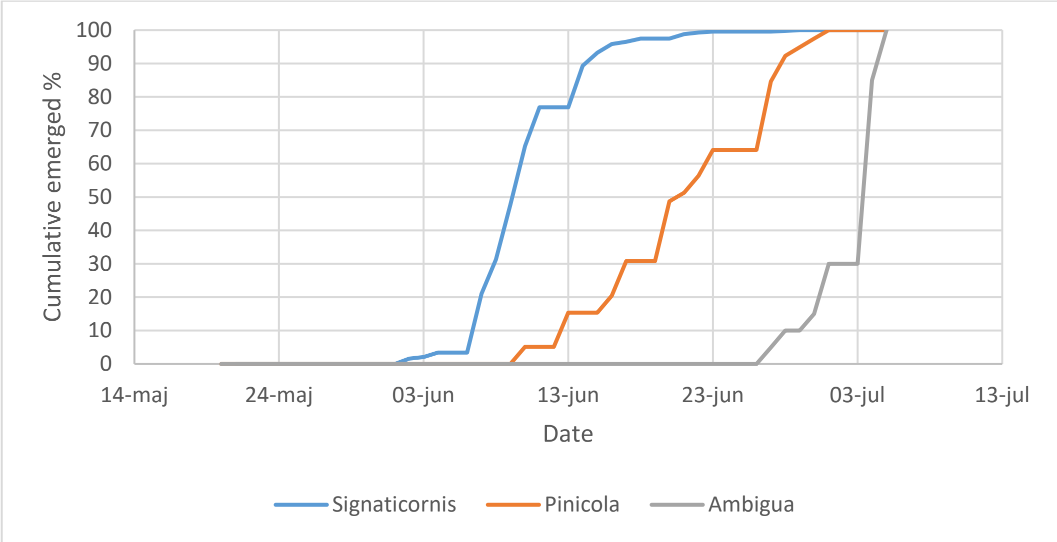

Figure 7. The mean cumulative percentages of emerged *M. signaticornis*, *M. Pinicola* and *M. ambigua*. Data from 11 logs recorded from 20th of May 2022 until 5th of July 2022.

3.2 Comparison emergence progression for 50% *M. Signaticornis* and *I. typographus*

The mean difference in number of days between *M. signaticornis* and *I. typographus* until ≥50% had emerged was 6.8 days for the 11 logs. The difference was significant (paired t-test, t=14.1, p<0.001). Means and Standard deviation (SD) for number of days until ≥50% had emerged are given in table 5.

Table 5. Number of days until ≥ 50% cumulative percentage had emerged for I. typographus and M. signaticornis from 11 logs. Data recorded from 20th of May 2022 until 1st of July 2022. N is the number of observations and mean is the mean number of days for each species.

	N	Mean	Sd
M. signaticornis 50%	11	20.55	2.841
I. typographus 50%	11	13.73	2.867

Treatment (degree of exposure) and species (*I. typographus* or *M. signaticornis*) explained a very high proportion of the variation in number of days until ≥ 50% had emerged (R^2=0.946). Most of the variation was explained by species, but also treatment had a strong effect (Table 6). There was no effect of the interaction between species and treatment (Table 6). Post hoc test showed significant difference between shadow and sun (ptukey= < .001) and shadow and intermediate (ptukey= < .001).

Table 6. Anova with number of days until ≥50% of total emergence was reached, as response variable and species (I. typographus, M. signaticornis) and treatments as independent variables. Data recorded from 20th of May 2022 until 1st of July 2022.

Cases	Sum of Squares	df	Mean Square	F	p	η^2
Species	248.07	1	248.07	187.515	< .001	0.604
Treatments	140.26	2	70.13	53.011	< .001	0.341
Species ✻ Treatments	1.49	2	0.74	0.561	0.581	0.004
Residuals	21.17	16	1.32			

Note. Type III Sum of Squares

3.3 Comparison of thermal sums for *Medetera* and *I. typographus* between treatments

There were differences between treatments in how large thermal sums that were reached when 25, 50 and 75 % of the *I. typographus* had reared out but no differences for *Medetera* spp. at the same percentages, tested in a one-way analysis of variance (Table 7).

Table 7. Results from Anova with interpolated thermal sums at 25, 50 and 75% of total emergence reached, as response variable species I. typographus, and as independent variables treatments. N is number of logs. Welch homogeneity corrections were applied. Data recorded from 20th of May 2022 until 1st of July 2022.

I. typographus	N	η^2	p
25 % emerged	11	0.805	0.007
50 % emerged	11	0.694	0.031
75 % emerged	11	0.675	0.032

4. Discussion

The aim of this study was to 1. Investigate the emergence progression of *Medetera* and *I. typographus* and 2. To examine if there were differences in emergence patterns between different *Medetera* species. The study revealed a time lag of about 7 days, between *M. signaticornis* and *I. typographus* until ≥ 50% cumulative percentage of each species had emerged. These results are from logs in closed emergence boxes and may not reflect the conditions in the forest where the time lag may be longer. From logs left in the forest, no *Medetera* were found after 7 days (Weslien 1992).

The number of days until ≥ 50% cumulative emergence differed between treatments but the time lag between *M. signaticornis* and *I. typographus* did not as indicated by the insignificant effect of the interaction between species and treatment (Table 6). In the forest, temperatures may differ since. *I. typographus*-killed trees within a forest will be subject to different degrees of sunlight with early and late emergence of both *I. typographus* and *M. signaticornis*. According to these results, there is not a prolonged time lag between the emergence of *I. typographus* and *Medetera signaticornis* due to shading.

A novel result of this study is that emergence patterns differed between the three *Medetera* species, where the dominant *M. signaticornis* starts emerging earliest and reached ≥50% cumulative emerged after 21 days whereas it took 33 days for *M. pinicola* and 46 days for *M. ambigua* (Figure 7). In this study there were only three species. However, there can be plenty more depending on local conditions. Hedgren & Schroeder (2004) found a total of at least eight species emerging from spruce trees killed by *I. typographus*. In that study *M. signaticornis* also dominated but *M. zinovjevi*, *M. piceae* and *M. setiventris* together accounted for about 30% of the individuals. In the light of the findings in this thesis it seems important to further investigate the phenology of different *Medetera* species.

Thermal sums

When comparing the mean cumulative emerged *Medetera* spp. and *I. typographus* and their mean thermal sums, a lag between the thermal sums can be observed (Figure 6). The differences when ≥50% cumulative percentages was reached at thermal sum 213.3 for *Medetera* spp. and 115.7 for *I. typographus*. The thermal sums (degree-days > 5 °C) at 25, 50 and 75% emerged *Medetera* did not differ significantly between treatments. However, for *I. typographus* temperature sums differed significantly at all percentages between treatments (Table 7). There is a possibility that the logs in the treatments sun and intermediate were drier than logs in shadow. If true, very dry bark may not be a preferable substrate for maturation feeding for *I. typographus* whereas shadow treatment might have offered moister bark. These hypothesized differences between treatments may hasten the emergence in treatments sun and intermediate compared to shadow. For *Medetera* spp. the emergence may be less dependent on the quality of bark and rather emerge as soon as they have hatched.

The assumption has been that the *Medetera* were in the larval stage when they were exposed to different treatments and therefore need to undergo developmental stages before emerging. Since no recorded thermal sums for *Medetera* are available, there is a possibility that *Medetera* needed to reach a certain threshold temperature to develop. If that is the case, the chosen threshold of 5 °C may not be applicable for *Medetera* and a higher threshold should be considered. If that should be true, it is possible that the number of *Medetera* in the shaded treatment may have continued to emerge if higher temperatures would have been reached. However, there was no significant difference in the thermal sums at 50% cumulative emerged for *Medetera* between different treatments which could indicate that the temperatures reached was high enough in the different treatments. A lower threshold than 5 °C could also have been chosen, however, from my own and colleague's observations, bark samples with *Medetera* stored at just below 5 °C for a few weeks, have not led to a noticeable increase in *Medetera* development. The threshold of 5 °C may therefore be applicable. The samples were however stored in a dark room so other important cues such as photoperiods were absent in this case.

Number of I. typographus and Medetera spp. per treatment and per tree

The number of emerged *I. typographus* differed slightly between treatments, all producing between 2000 and 3000 individuals (Figure 2). For *Medetera* the difference was more prevalent, where the number of individuals was about twice as high in the sun treatment and intermediate treatment as in the shadow treatment (Figure 3). Factors such as moisture, heat and light may be affecting the number of emerged individuals in the different treatments. There was also a pattern that more *Medetera* spp. and fewer *I. typographus* emerged from tree A than tree B (Table 3). *Medetera* predation may be causing this difference but since there are no replicates of trees (df=1) conclusions should be careful.

Intermediate treatment faster than sun treatment

The number of days until at least 50% cumulative emerged occurred faster for both *M. Signaticornis* (Figure 5) and *I. typographus* (Figure 4) in the intermediate treatment than in the sun treatment. Possible reasons could be that the intermediate treatments placement did not actually represent an intermediate temperature. The intermediate treatment was somewhat wind protected and at the same time had some sun. The sun treatment had full sun but was not wind protected (since it would have shaded). The combination of wind protection and some sun may have led to the intermediate treatment reaching higher temperatures than sun and thereby earlier emergences.

Practical implications

The number of days until ≥ 50% cumulative emergence differed between treatments but the time lag between *M. signaticornis* and *I. typographus* did not (Table 6). On a smaller scale, temperatures within a forest may also differ. *I. typographus*-killed trees within a forest will be subject to different degrees of sunlight with early and late emergence of both *I. typographus* and *Medetera.* According to these results, there is not a prolonged time lag between the emergence of *I. typographus* and *Medetera* due to shading.

To decrease bark beetle attacks by *I. typographus* a performed practice is to remove the bark beetle killed trees as soon as possible after the attack and thereby remove the bark beetles from the forest (Schroeder & Fritscher 2020). If this is done it can prevent the beetles from developing a new generation. The economic losses may be reduced with this practice (Schroeder 2007a). This study indicates that the time window between *I. typographus* attack and the colonization by *M. signaticornis* is quite short and that it is virtually impossible to detect, cut and remove newly spruce bark beetle-attacked trees before *M. signaticornis* also has colonized them. However, early removal of attacked trees during spring and summer, that contain both *I. typographus* and *Medetera* progeny, is still better than late removal during fall, winter and spring when many *I. typographus* have left the trees but all the *Medetera* are still in larval stage in the bark. In that case it might be a better option to wait until *Medetera* flies have emerged in spring which according to this study is at least one week after *I. typographus* has left.

Even though the long-legged flies are considered an important natural enemy of spruce bark beetles they are currently not being used as biocontrol agents. However, Sousa et al. (2023) brings forth the idea that it might be possible in the future and points out that the species *M. signaticornis* is suitable. From experiments using *M. signaticornis,* Sousa et al. (2023) were able to attract the long-legged flies using a synthetic blend that mimics relevant host cues. The results of the study could be implemented in practice to help monitor long-legged flies of the genus *Medetera* and can also be used as a means to increase the number of flies at local bark beetle outbreaks. This, according to Sousa et al. (2023), might decrease the amount of bark beetles in attacked trees which in turn can help mitigate economic losses.

4.1. Conclusion

This study shows for the first time how *I. typographus* and *Medetera* spp. responds to accumulating thermal sums after overwintering. Despite being well documented and an important predator of *I. typographus,* very little is known about the phenology of different *Medetera* spp. There are still many knowledge gaps, e.g., flight thresholds for different *Medetera* species and their relationship to other hosts than *I. typographus.* This study brings some new knowledge on the differences in phenology between different *Medetera* species and between *M. signaticornis* and *I. typographus.*

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Populärvetenskaplig sammanfattning

Granbarkborren (*I. typographus*) är en skadeinsekt som under vissa förhållanden kan orsaka enorma skador på granskog. Skalbaggen angriper vanligen stormfällda träd men de kan även attackera stående, levande träd när populationerna är höga. För att bekämpa granbarkborrar är en vanlig metod att söka upp nyligen angripna träd och avverka och ta bort dessa från skogen, innan larverna hunnit kläckas och flyga i väg. Skador på skog orsakat av granbarkborrar kan också begränsas av andra typer av insekter som under hela eller delar av sin livscykel utgör naturliga fiender till granbarkborren. En av de vanligaste fienderna till granbarkborrar är styltflugor av släktet *Medetera*. En ökad kunskap om granbarkborrens fiender är viktigt för att åtgärder i skog, som exempelvis tidig avverkning, ska kunna anpassas för att inte påverka fienderna negativt.

I min studie undersökte jag kläckningsförloppet hos *Medetera*-arter och granbarkborren *I. typographus* efter att de övervintrat och hur dessa arters kläckning är kopplad till olika temperaturer. Jag jämförde även om kläckningsförloppet skiljer sig mellan olika *Medetera*-arter. Två granbarkborredödade träd kapades och lades i fångstlådor med tre olika solexponeringar: sol, mellan och skugga, under perioden 20 maj till 5 juli 2022. Granarna som användes var från Korpboström utanför Uppsala och experimentet utfördes i Uppsala. Inne i lådorna mättes temperaturen kontinuerligt under hela experimentet och insekterna som kläckts fram ut ur stockarna fångades i en burk och registrerades dagligen. Kläckningsförloppen studerades genom att mäta antal dagar från experimentets början till dess att minst 50% av arterna kläckts. Totalt fångades 7600 *I. typographus* och 495 individer av *Medetera*-arter, varav arten *M. signaticornis* var den vanligaste (432 fångade individer).

En helt ny upptäckt i denna studie var skillnaden i kläckningsförlopp hos de tre *Medetera* arterna som kläcktes ut. I studien fann jag att den mest rikligt utkläckta arten (*M. signaticornis*) också var den tidigaste, där 50% fångats efter 21 dagar. De två andra arterna *M. pinicola* och *M. ambigua* behövde 33 respektive 46 dagar. Resultatet från studien visade även att det skiljer sig ungefär sju dagar mellan att *I. typographus* och *M. signaticornis* kläcks fram oavsett solexponering. Detta tidsspann är så kort att det blir svårt att hinna hitta, hugga ner och ta ut nyligen attackerade granar ur skogen innan *Medetera*-arterna hinner lägga sina ägg i granarna. Detta innebär att man riskerar att även plocka ut fienderna ur skogen.

Trots att det sedan tidigare är känt att *Medetera*-arter är viktiga predatorer till granbarkborrar, finns det kunskapsluckor kring deras kläckningsförlopp och interaktion med andra insekter. Resultatet från min studie ökar kunskapen om skillnaden i kläckningsförloppet mellan olika *Medetera*-arter samt mellan *M. signaticornis* och *I. typographus* och kan därför bidra till ny kunskap kring hur angripna träd kan hanteras.

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