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A theoretical approach to the pale tussock moth outbreak in Turkey

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Abstract: The pale tussock moth, *Calliteara pudibunda*, makes periodic outbreaks in Europe. The species made an unusual outbreak between 2018 and 2019 in Bursa, Turkey. The aim of this study is to investigate occurrence of any previous outbreak of the species in Turkey, and possible relationship among the forest management activities, temperature trends, and the recent outbreak. To investigate previous outbreaks, scientific reports, and theses both in English and Turkish, along with nature photography repositories and forums from Turkey were searched. Additionally, a questionnaire was conducted with retired Turkish foresters. Annual forest management reports related to the outbreak stand were reviewed to evaluate possible impact of the forest management activities conducted in the stand prior to the outbreak. Finally, change of size in a hypothetical *C. pudibunda* population was simulated by using different pupal mortality rate – temperature scenarios to predict the conditions under which an outbreak can occur. As a result, no evidence of a *C. pudibunda* outbreak prior to 2018 was found in Turkey. Forestry management reports revealed that two consecutive clear-cutting activities were conducted in 2012 and 2013 to open a power line in the outbreak stand. The temperature regime between 2008 and 2018 caused a dramatic increase in the simulated *C. pudibunda* populations.
Keywords: *Calliteara pudibunda*, Outbreak history, Forest management, Clear-cutting, Pupal mortality

Türkiye'de yaşanan kızıl kuyruklu kayın tırtılı epidemisine kuramsal bir yaklaşım

Özet: Kızıl kuyruklu kayın tırtılı, *Calliteara pudibunda*, Avrupa'da periyodik epidemiler yapar. Tür, 2018-2019 yılları arasında Bursa, Türkiye'de olağandışı bir epidemi yapmıştır. Bu çalışmanın amacı, türün Türkiye'de daha önce herhangi bir epidemi yapıp yapmadığını ve orman amenajman faaliyetleri, sıcaklık eğilimleri ve son epidemi arasındaki olası ilişkiyi araştırmaktır. Daha önceki salgınları araştırmak için hem İngilizce hem de Türkçe bilimsel raporlar ve tezler ile Türkiye'den çevrimiçi doğa fotoğrafçılığı site ve forumları taranmıştır. Ayrıca emekli ormancılarla bir anket yapılmıştır. Salgın öncesi meşcerede yürütülen orman amenajman faaliyetlerinin olası etkilerini değerlendirmek için epideminin gerçekleştiği meşcereye ilişkin yıllık orman amenajman raporları gözden geçirilmiştir. Son olarak, varsayımsal bir *C. pudibunda* popülasyonundaki büyüklük değişimi, bir epideminin meydana gelebileceği koşulları tahmin etmek için farklı pupa ölüm oranı – sıcaklık senaryoları kullanılarak simüle edilmiştir. Sonuçta, Türkiye'de 2018'den önce bir *C. pudibunda* epidemisi olduğuna dair herhangi bir kanıt bulunamamıştır. Orman amenajman raporları, epidemi bölgesinde bir elektrik hattı açmak için 2012 ve 2013 yıllarında iki ardışık tıraşlama faaliyetinin gerçekleştirildiğini ortaya koymuştur. 2008 ve 2018 arasındaki sıcaklık rejimi, simüle edilmiş *C. pudibunda* popülasyonlarında çarpıcı bir artışa neden olmuştur.
Anahtar kelimeler: *Calliteara pudibunda*, Epidemi geçmişi, Orman işletmesi, Tıraşlama kesimi, Pupa ölüm oranı

1. Introduction

Climate change can affect the activity of native insect species that previously posed no significant threat to forests (Tenow et al., 1999). This could either be a result of increasing drought-related host tree stress (Logan et al., 2003) or increasing insect feeding activity as a response to rising temperature (Jawrowski & Hilszczański, 2013), or both.

The pale tussock moth, *Calliteara pudibunda* (L. 1758) (Lepidoptera; Erebidae), is a defoliator species native to Northwestern Palearctic with a few occurrences from Eastern Asia (Trofimova, 2012). Its larvae are herbivorous, and they can cause complete defoliation of deciduous stands, mainly beech, during outbreak periods (Mazzoglio et al., 2005). Local populations of *C. pudibunda* make periodic outbreaks in Europe generally once in every 20-30 years, and these outbreaks end suddenly after two to three years (Mazzoglio et al., 2005). Although the outbreak range in Europe had been thought to be between the 48th and the 57th parallels, Mazzoglio et al. (2005) reported an outbreak below the 48th parallel in northwestern Italy. It has recently made an epidemic even further south (between 39th and 40th parallels) between 2018 and ended in 2019 in Bursa Province (İnegöl), Turkey (Sarıkaya et al., 2021), and caused complete defoliation in *Fagus orientalis* Lipsky stands in areas of ca. 50 and 453 ha, respectively (Açıcı, 2021), suggesting either that its outbreak range is larger than it was known before, or it is getting larger or shifted due to the changing climate.

Increasing temperature reduces the larval and pupal mortality in many lepidopterans (e.g., Karolewski et al., 2007; Du Plessis et al., 2020). As *C. pudibunda* overwinters in the pupa stage, winter temperature could be an important

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factor limiting its population growth (Mazzoglio et al., 2005). Therefore, evaluating possible reduced mortality scenarios based on the recorded temperatures in the region could be informative in understanding the reason of the recent outbreak in Turkey. Additionally, previous possible *C. pudibunda* outbreak incidences should be investigated carefully to understand its population fluctuation dynamics in Turkey and to estimate future outbreaks.

The present study focuses on the following questions: (1) Did *C. pudibunda* make any outbreak in Turkey prior to the recent one in Bursa Province? (2) Can temperature trends along with the forest management activities in the region and the recent *C. pudibunda* outbreak be related?

2. Materials and methods

Three types of sources were used to investigate a possible previous invasion by *C. pudibunda* in Turkish deciduous forests: (1) Google Scholar and Thesis Center of the Turkish Council of Higher Education with the keywords "*Calliteara pudibunda* + Turkey", "*Dasychira pudibunda* + Turkey" and "kayın tırtılı" (beech caterpillar); (2) Five senior or retired foresters who worked particularly in the northwestern deciduous forests of Turkey where recent *C. pudibunda* invasion has been recorded (Simply, a photograph of the last instar larva which is not easily overlooked due to its bright yellow color, a red tail and tussock appearance, was showed to the retired foresters and they were asked to report if they had ever seen the species during their professional life in which they frequently visited their stands of responsibility); and (3) amateur nature photography repositories and forums from Turkey with the keywords "sarı tırtıl" (yellow caterpillar) and "kırmızı kuyruklu tırtıl" (red tailed caterpillar). Additionally, annual forest management reports related to the outbreak stand in Bursa for the years between 2008 and 2018 were reviewed to evaluate any possible impact of the forest management activities conducted in the stand prior to the outbreak.

In the next step, a hypothetical *C. pudibunda* population which has a pupal mortality rate of 95% per year which decreases by increasing temperature was assumed (such high natural pupal mortality rates for lepidopterans pupating in the litter have been reported by several researchers, e.g., Robertson and Hoffmann, 1989; Turnock and Bilodeau, 2012). The following six different lower mortality rates were assumed in years warmer than the average: 90%, 85%, 80%, 70%, 60%, and 50%. Then, the possible number of larvae were calculated under each mortality rate and average temperature recorded for the period between 2008 and 2018 to predict how many years it takes for *C. pudibunda* to make an outbreak. For this purpose, monthly average temperatures recorded in the region for the given period were obtained from the Bursa Meteorological Station, and the population growth calculation was conducted as such: initially 1000 hypothetical pupae were assumed to occur in 2008, 95% of which were assumed to die as the winter of 2008 was colder than the average, and 5% of them produced the next generation. As the winter of 2009 was warmer than the average, the mortality rate was assumed to drop to one of the six lower mortality rates given above, and the number of larvae in 2009 were calculated for each mortality rate. This annual calculation was made until 2018 by using the number of eggs per female as 40 (Göktürk and Aksu, 2005), and assuming zero egg parasitism along with 50:50 population sex ratio. The following formula was used to calculate the hypothetical number of larvae produced each year:

$$L = \frac{(P - [P \text{ x } M])}{2} \text{ x } 40$$

where L is the number of larvae, P is the number of pupae, M is the mortality rate, ½ is to remove the adult males, and 40 is the number of eggs produced per female per year.

Finally, in order to determine pupal parasitoids, the outbreak spot in Bursa Province (39.954053° N - 29.662014° E) was visited in 29.04.2019 and 100 pupae were collected and kept in separate falcon tubes (50 ml), each with a ventilated lid, under room temperature and natural photoperiod conditions with daily checks until adult moths emerged.

3. Results

Throughout an exhaustive literature search, 17 papers and a thesis completely or partly on *C. pudibunda* were found from Turkey, reaching back to 1943. Only three of them, published in 2019 and 2021, mentioned the outbreak in 2018 and 2019 in Turkey. The rest was either on the occurrence of the species or its parasitoids and predators. None of the five interviewees, neither senior nor retired foresters, who worked in the northwestern forests of Turkey between 1970 and 2000, recalled any outbreak caused by *C. pudibunda*, and three of them even did not recognize the species. Finally, only one photograph of the species taken by an amateur nature photographer before 2018 in Turkey was found. It was a photograph of a single last instar larva walking on the ground taken in 2011 in Bolu Province, northwestern Turkey. As a result, it seems reasonable to conclude that *C. pudibunda* outbreak is a recent phenomenon in Turkish deciduous forests and did not occur before 2018. Reviewing the forestry management reports of the local department of forestry revealed that two consecutive clear-cutting activities were conducted in 2012 and 2013 to open a power line in the stand where the outbreak started. As a result, at least 1 ha was clearcut and 400 m^3 beech log was produced in these years (Figure 1).

Plotting the average temperatures against months between 2008 and 2018 revealed that the year 2018, especially the winter, was warmer than the mean of the previous 10 years (Figure 2a). There was no significant difference in precipitation and humidity between 2018 and before. The hypothetical 5%, 10%, 15%, 25%, 35% and 45% decreases in mortality in warmer winters were found to be able to cause a dramatic increase in the number of *C. pudibunda* larvae in 10 years; the hypothetical *C. pudibunda* population became 16, 81, 256, 1296, 4096 and 10,000 times bigger, respectively, than the starting population under different mortality rate scenarios and the temperature pattern in Bursa Province between 2008 and 2018. The highest numbers of larvae were reached in 2015 in each scenario, and then they remained unchanged (Figure 2b) (Table 1).

Among 100 pupae reared under laboratory conditions, 82 *C. pudibunda* adults emerged (47 females:35 males) almost simultaneously after five weeks without any parasitoid emergence in the meantime and in the following six months. Non-emerged cocoons were dissected after six months. There was no sign of parasitoids in dead and dried pupal remains.

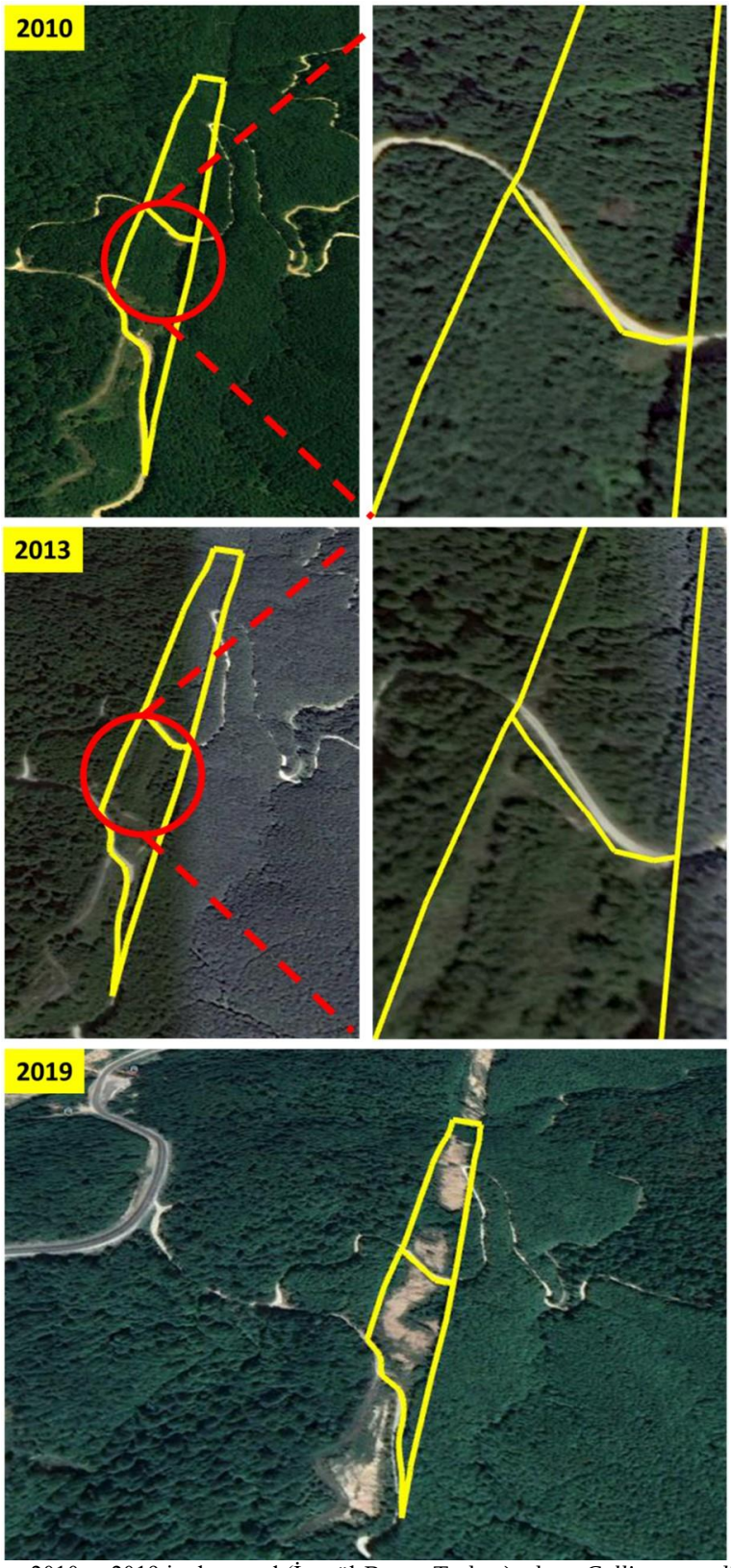

Figure 1. Clear-cutting from 2010 to 2019 in the stand (İnegöl-Bursa, Turkey) where *Calliteara pudibunda* outbreak started in 2018

Table 1. The number of larvae produced each year by the hypothetical *Calliteara pudibunda* population under different mortality rates and recorded temperature in Bursa, Turkey

Year	Number of larvae under different mortality rates					
	50%	60%	70%	80%	85%	90%
2008	1000	1000	1000	1000	1000	1000
2009	1000	1000	1000	1000	1000	1000
2010	10000	8000	6000	4000	3000	2000
2011	100000	64000	36000	16000	9000	4000
2012	100000	64000	36000	16000	9000	4000
2013	100000	64000	36000	16000	9000	4000
2014	1000000	512000	216000	64000	27000	8000
2015	10000000	4096000	1296000	256000	81000	16000
2016	10000000	4096000	1296000	256000	81000	16000
2017	10000000	4096000	1296000	256000	81000	16000
2018	10000000	4096000	1296000	256000	81000	16000

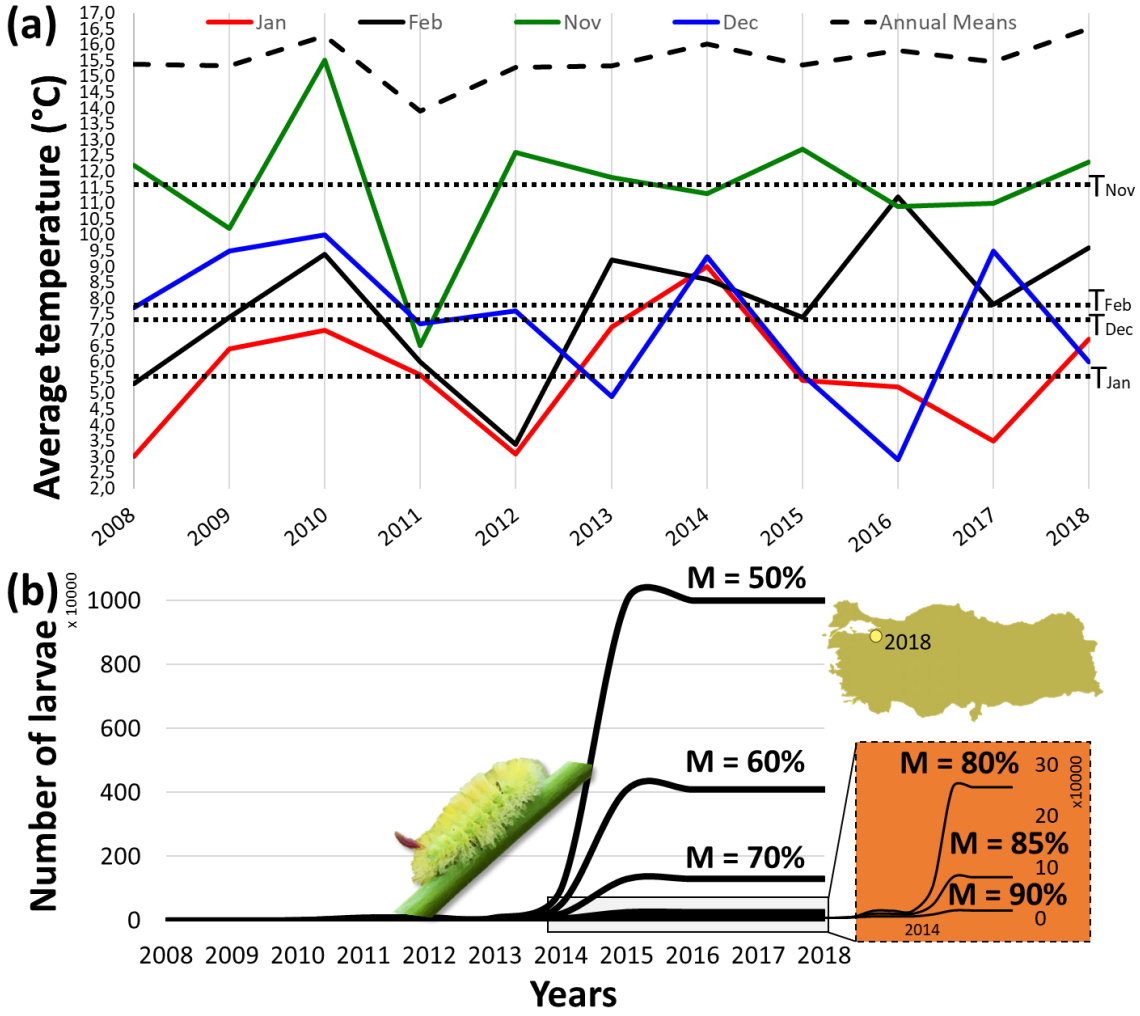

Figure 2. (a) Average winter temperatures between 2008 and 2018, (b) simulated number of *Calliteara pudibunda* larvae produced annually between 2008 and 2018 under different "mortality rate (M) – recorded temperature" scenarios for Bursa Province, Turkey

4. Discussion

The theoretical framework that was set in this study suggested that when the other parameters of population growth (such as the effects of possible fluctuations in natural enemy populations) are assumed null, *C. pudibunda* population can reach an outbreak level as a result of higher temperatures than normal.

The pest made an outbreak in 2018 and 2019 in beech forests of Bursa Province, northwestern Turkey. This means that the known outbreak range of the species expanded or shifted. It should be monitored over the next few decades to draw a conclusion about the periodicity of *C. pudibunda* outbreaks in Turkey. No historical record or observation suggesting a previous outbreak of the species in the country were found.

Pale tussock moth outbreaks in Europe, at least some of them, were related to warmer and drier summers than normal (Mazzoglio et al., 2005). This is a general response of many insect species including moths to rising temperature (e.g., Battisti, 2008). The winter of 2018 in Bursa was relatively warmer than the previous 10 years. Actually, 2018 was the second warmest year recorded since 1971 in the whole country (2011 was the warmest). While the average temperature for the period between 1981 and 2010 was 13.5°C, it was 15.4°C in 2018. Additionally, the warmest February, July, August, and September of the last 90 years in Bursa occurred after 2010 (MGM, 2021). Therefore, not only 2018 but also the last decade was warmer than before, and this could be one of the main reasons of the recent *C. pudibunda* outbreak in the region. Effects of increasing temperature can be quite diverse on insects, one of which could be reduced overwintering mortality (Paradis et al., 2008). The pale tussock moth overwinters as a pupa in the litter, and it is probably sensitive to changes in the temperature and humidity (Mazzoglio et al., 2005). According to Zwölfer and Postner (1954), outbreak threshold for *C. pudibunda* is four viable pupae per m^2. Such a link between the number of pupae and outbreak possibility suggests that understanding the factors affecting pupal mortality in this species is significant for understanding its outbreak dynamics. The straightforward calculation in this study showed that if air temperatures above the average reduced the winter mortality of *C. pudibunda* pupae (even as low as 5%), the climate pattern between 2008 and 2018 could result in a significant population growth at the end of 10 years. It should be kept in my mind that my population growth calculations are based on the lowest number of eggs per female (40) in the relevant literature, which is most probably an underestimation of the species' reproductive capacity as the highest number of eggs per *C. pudibunda* females has been reported as 400 (Meullengracht-Madsen and Nielsen, 2022). When the same calculation was repeated with higher egg numbers, it was found that the population growth in an outbreak level can be reached in a couple of years even under the assumption of 95% pupal mortality. Impact of forest management activities in the considered stands could be another cause of the unusual *C. pudibunda* outbreak in Turkey. Multilayered stands with uneven-aged management tend to suffer from less insect damage probably because several independent reasons such as multilayered forests causing lower reproduction rates of insect pests or trees regenerated naturally in such forests are more resilient to insect attacks (Björkman et al., 2015). Additionally, since humidity is a significant limiting factor for insects that pupate in the litter, such as *C. pudibunda*, due to the action of bacteria, fungi, and/or nematodes is favored by the humid environments (e.g., Kaya and Haya, 1981), decrease in humidity because of forest management activities could decrease the mortality of the pest insect species. The same activities could also decrease the impact of parasitoids as they may suffer more than their hosts from a decrease in humidity (Hance et al., 2007) or phenological asynchrony between the parasitoid and the host as a result of faster development of one of the components in the interaction (Fleming, 1996). According to the forest management reports reviewed in the present study, due to a power line construction project, a clear-cutting was applied on at least 1 ha in 2012 and 2013 in the even-aged stand where the outbreak started in 2018. This fact along with the increasing temperature could cause a decrease in the winter mortality of the moth through some of the mechanisms described above, which could eventually bring its local population to an outbreak level. The rearing results of this study suggested a quite low rate of larval/pupal parasitism for *C. pudibunda* even in the second year of the outbreak. This is in parallel with the low parasitism rates during outbreaks reported in Europe (Mazzoglio et al., 2005). On the other hand, the sampling size in this study is not sufficient for further interpretation of the parasitoid abundance. Moreover, as parasitism rate in non-outbreak populations of *C. pudibunda* is not known which makes a robust comparison impossible for now, the relationship between *C. pudibunda* outbreaks and the parasitoids remains a topic for future studies. The discussion so far has been on the causes of the outbreak, but there are also some observations about how it ended which could be integral to the causes. The outbreak in Turkey ended suddenly in two years with the sight of thousands of dead caterpillars hanging on the branches as prolegs attached to the branch and a strong odor of decay (M. Tok, pers. com.). This is a general observation in all *C. pudibunda* outbreaks in Europe and the cause is thought to be a virus outbreak among the larvae (Mazzoglio et al., 2005). Although the Turkish General Directorate of Forestry applied *Bacillus thuringiensis* var. *kurstaki* (*Btk*) preparations during the second year of the outbreak in a limited stand, the same sight and odor were also observed in the other stands in the vicinity where no *Btk* applied. Thus, the virus outbreak hypothesis should also be considered to explain the termination of the outbreak in Turkey. Regardless of how the recent outbreak started or ended, it is certain that it caused an extensive defoliation in the beech stand in Bursa (Ö. Açıcı, pers. com.). Considering the results of Dağtekin et al. (2020), who predicted a contraction in the beech distribution in Bursa Province even with an optimistic future scenario, outbreaks of *C. pudibunda* can be seen as another threat for the beech stands in the near future. Consequently, many aspects of the recent *C. pudibunda* outbreak in Turkey remain unknown and necessitate a long-term monitoring.

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