Evaluation of the counting success of pheromone-baited trap with electronic control unit

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Pheromone-baited traps are used to monitor bark beetle adult populations for pest management. In the present study, beetles have been counted using a pheromone-baited trap prototype, with electronic control unit. The recording success of their instant date, hour, temperature and humidity parameters have been evaluated. In the tests, 87.1% of the beetles has been counted and recorded. The reliability of the instant parameters has been verified with external equipment. Although the counting success ratios of the tests conducted in dark and under daylight conditions vary in a statistically significant manner, they are close to each other, i.e. 83.7% and 90.2% respectively. A statistically significant difference has not been detected between the counting success of these throwing frequencies, and the counting success ratios vary between 80.7% and 91.8%. When the beetles were thrown by groups of two, three and four in the trap at the same, it has also been found that at least 83.3% of the beetles can be counted successfully in the tests.

Keywords: Bark beetle, counting success, electronic control unit, pheromone-baited trap.

BARK beetles (Coleoptera: Curculionidae: Scolytinae), which play a key role in the natural plant communities and large-scale habitats, are important elements of the ecosystem[1], particularly in the forests[2]. Even though their effects on forest ecosystems are not always destructive[3], bark beetles are as effective on forest dynamics as to change the forest[4]. They may lead to ecosystem disrupt as a result of their outbreak and, then cause economic[5] and ecologic losses.

The occurrence of bark beetle outbreak and subsequent tree deaths is common in forests. In Turkey[6–10] and around the world, conifer forests are under threat due to bark beetle outbreaks[11–14]. As a result of such outbreaks, great losses may occur in the forests[15]. An annual average of 300,000–400,000 m^3 unplanned cutting due to outbreak of the species in the conifer forests, Turkey and 1 million m^3 unplanned cutting when beetle populations are severe has been reported[16]. This situation not only causes serious losses to national wealth of a country, but also has negative effects on the forest ecosystem balance. In order to ensure the sustainability of healthy forests and to balance forest ecosystem dynamics, biological, mechanical and biotechnical methods as well as integrated management methods are being utilized. The beetle pheromones, which are widely used in the monitoring of adult populations of endemic pest species in these methods[17], make positive contributions to the pest control programmes[18].

The aggregation pheromone, which plays an important role in the life cycle of these beetles[5], is preferred during massive attack coordination[19], and determination and measurement of population levels[20]. Even though there are experimental and technical problems in the extensive use of pheromones[17,21], pheromone-baited traps are biotechnical elements that facilitate the detection of pests, their monitoring, and in the determination of their population density. Although problems related to the monitoring of beetles exist in forestry practices[22], determination of the change in population density at the endemic damage level of the target species has been sustained successfully through these traps for many years[17]. In this monitoring process, the aim is not to take beetle populations under control[20]. This utilization is an effective method, especially in monitoring aggressive forest pest outbreaks[23], collecting records of population changes[9], explaining beetle ecology[24], and determining the time for utilization of the repression plan[20]. The traps that are used nowadays provide information only on the number of beetles that are captured depending on the control intervals. No information is provided about temperature and humidity parameters at the exact time of capture[25].

Bark beetles, which can lead to limited or extensive number of tree deaths in large areas due to their outbreaks under suitable conditions, cause serious losses in forests. According to Drooz[26], large-scale outbreaks of bark beetles cannot be controlled by humans. However, effective management pest control to ensure sustainability of a

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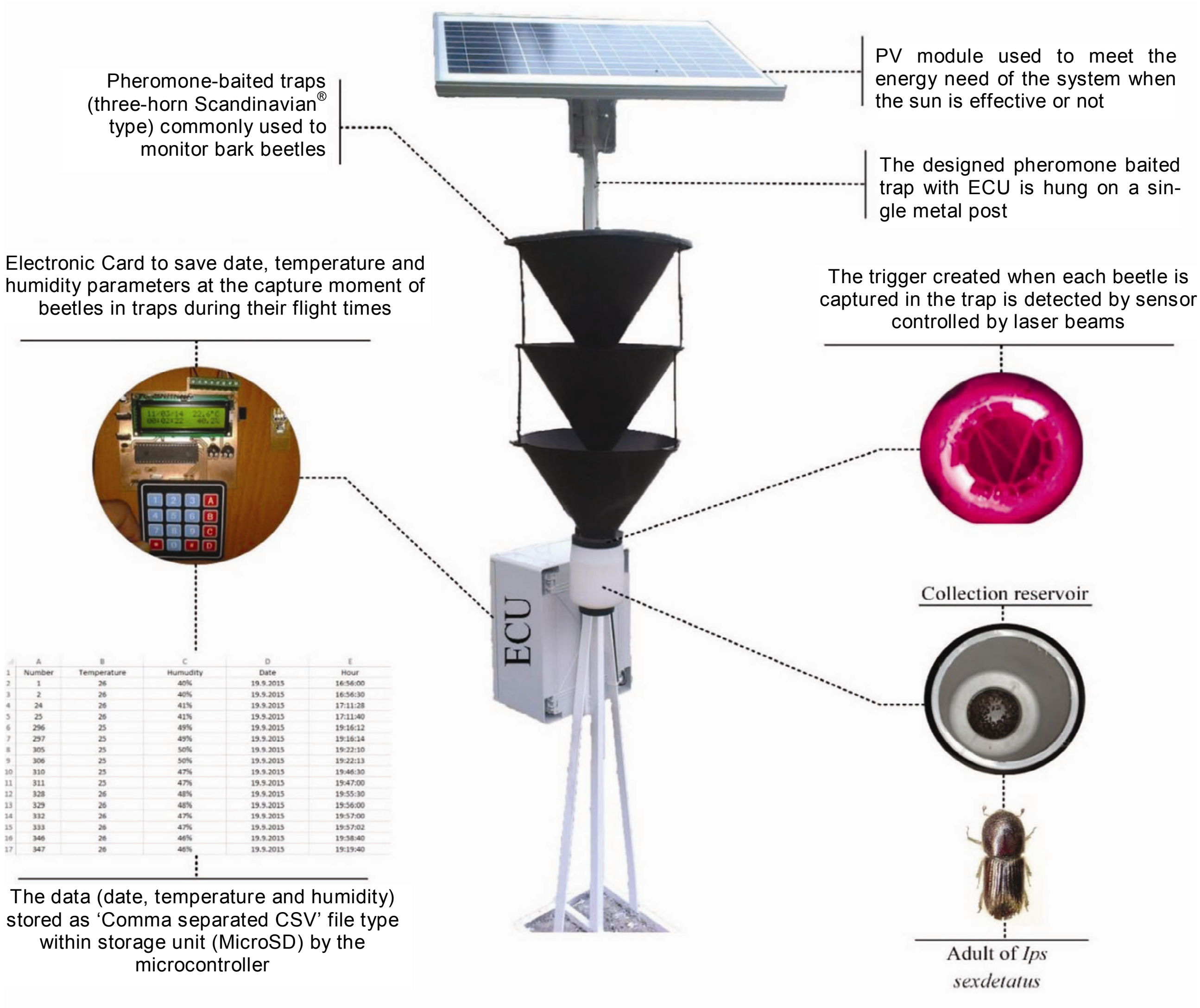
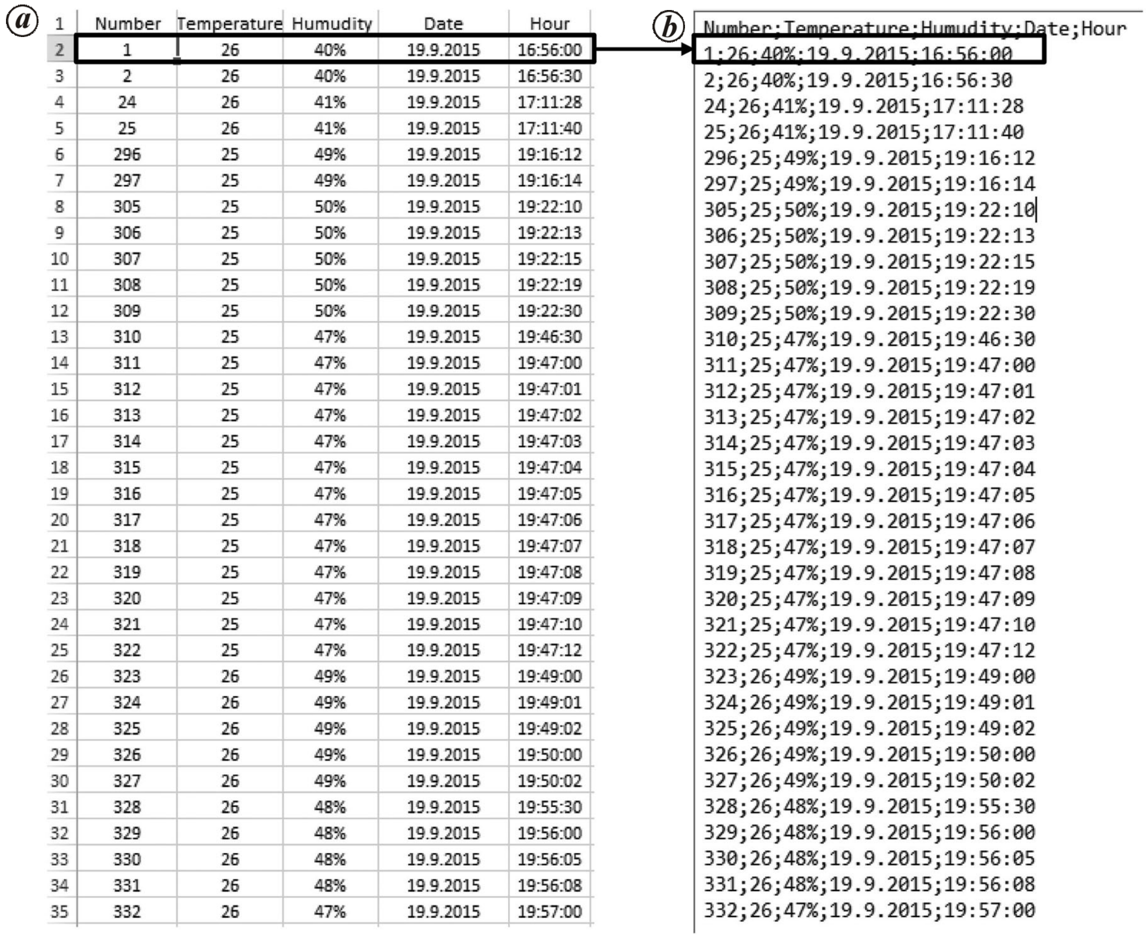


Figure 1. Design of prototype electronic control unit and system equipment.

healthy ecosystem is important in terms of future existence of forests. A pheromone-baited trap with electronic control unit (ECU) has been designed to study bark beetle ecology and biology; and to develop management strategies for the targeted species, and to record the number of captured beetles as well as other important parameters during their time of capture (date, day, year, hour, temperature and humidity)[25]. In this study, the quantitative performance of the designed pheromone-baited trap with ECU has been evaluated. The beetle throws at different predetermined time intervals and without intervals, and the counting results and success of the designed mechanism under natural application field conditions (in dark and under daylight condition) have been evaluated. The results obtained may contribute to a decrease in the destruction of forests due to these beetles. It may also provide that effectively using pheromone-baited traps at the monitoring of the beetles and the determination of their population density.

Materials and methods

A total of 1141 *Ips sexdentatus* (Boerner) (Coleoptera, Curculionidae, Scolytinae) adults were used in this study. The ECU (see Ozcan *et al*.[25] for details) was set up using the required equipment and a prototype mechanism was developed for the pheromone-baited trap. A laser scanning application (laser diode, photocell, etc.) was used to determine the exact time of capture of the beetle by the trap and its fall into the trap chamber. Breakage of laser beams, triggering at the time of fall of the beetle, and the time, temperature and humidity parameters were recorded in a microSD card using the ECU. The recorded parameters were stored as 'Comma separated CSV' file within the microSD card using a microcontroller. The photovoltaic system was utilized in order to meet the energy required for the unit and to carry out the counting process completely in the pre-determined duration[25] (Figure 1).



(a)

	Number	Temperature	Humudity	Date	Hour
2	1	26	40%	19.9.2015	16:56:00
3	2	26	40%	19.9.2015	16:56:30
4	24	26	41%	19.9.2015	17:11:28
5	25	26	41%	19.9.2015	17:11:40
6	296	25	49%	19.9.2015	19:16:12
7	297	25	49%	19.9.2015	19:16:14
8	305	25	50%	19.9.2015	19:22:10
9	306	25	50%	19.9.2015	19:22:13
10	307	25	50%	19.9.2015	19:22:15
11	308	25	50%	19.9.2015	19:22:19
12	309	25	50%	19.9.2015	19:22:30
13	310	25	47%	19.9.2015	19:46:30
14	311	25	47%	19.9.2015	19:47:00
15	312	25	47%	19.9.2015	19:47:01
16	313	25	47%	19.9.2015	19:47:02
17	314	25	47%	19.9.2015	19:47:03
18	315	25	47%	19.9.2015	19:47:04
19	316	25	47%	19.9.2015	19:47:05
20	317	25	47%	19.9.2015	19:47:06
21	318	25	47%	19.9.2015	19:47:07
22	319	25	47%	19.9.2015	19:47:08
23	320	25	47%	19.9.2015	19:47:09
24	321	25	47%	19.9.2015	19:47:10
25	322	25	47%	19.9.2015	19:47:12
26	323	26	49%	19.9.2015	19:49:00
27	324	26	49%	19.9.2015	19:49:01
28	325	26	49%	19.9.2015	19:49:02
29	326	26	49%	19.9.2015	19:50:00
30	327	26	49%	19.9.2015	19:50:02
31	328	26	48%	19.9.2015	19:55:30
32	329	26	48%	19.9.2015	19:56:00
33	330	26	48%	19.9.2015	19:56:05
34	331	26	48%	19.9.2015	19:56:08
35	332	26	47%	19.9.2015	19:57:00

(b)

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Number;Temperature;Humudity;Date;Hour
1;26;40%;19.9.2015;16:56:00
2;26;40%;19.9.2015;16:56:30
24;26;41%;19.9.2015;17:11:28
25;26;41%;19.9.2015;17:11:40
296;25;49%;19.9.2015;19:16:12
297;25;49%;19.9.2015;19:16:14
305;25;50%;19.9.2015;19:22:10
306;25;50%;19.9.2015;19:22:13
307;25;50%;19.9.2015;19:22:15
308;25;50%;19.9.2015;19:22:19
309;25;50%;19.9.2015;19:22:30
310;25;47%;19.9.2015;19:46:30
311;25;47%;19.9.2015;19:47:00
312;25;47%;19.9.2015;19:47:01
313;25;47%;19.9.2015;19:47:02
314;25;47%;19.9.2015;19:47:03
315;25;47%;19.9.2015;19:47:04
316;25;47%;19.9.2015;19:47:05
317;25;47%;19.9.2015;19:47:06
318;25;47%;19.9.2015;19:47:07
319;25;47%;19.9.2015;19:47:08
320;25;47%;19.9.2015;19:47:09
321;25;47%;19.9.2015;19:47:10
322;25;47%;19.9.2015;19:47:12
323;26;49%;19.9.2015;19:49:00
324;26;49%;19.9.2015;19:49:01
325;26;49%;19.9.2015;19:49:02
326;26;49%;19.9.2015;19:50:00
327;26;49%;19.9.2015;19:50:02
328;26;48%;19.9.2015;19:55:30
329;26;48%;19.9.2015;19:56:00
330;26;48%;19.9.2015;19:56:05
331;26;48%;19.9.2015;19:56:08
332;26;47%;19.9.2015;19:57:00
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Figure 2. The ®Excel (***a***) and Notepad (***b***) print screens of data recorded in CSV format.

I. sexdentatus was preferred for the study, as it is easy to obtain. The species was collected in the black pine forests of the Kastamonu province in Turkey in July 2015, at different dates. The barks of the trees which had been damaged before the flight of adults were removed using an axe and numerous adult beetles were brought to the laboratory in plastic bags. Dead adult beetles that were chosen among those collected were used during the tests. Five different throwing intervals were determined: very often (1 sec timescale), often (5 sec timescale), rare (15 sec timescale), very rare (1 min timescale) and random (uncontrolled timescale) in order to indicate the quantitative success of counting results, and the throws were carried out. In addition, considering the possibility of capturing the beetles in the trap at the same time, they were thrown in groups of two, three and four, and the results were evaluated. The beetles were thrown by hand at these pre-determined frequencies by making them hit the funnels of a ®Scandinavian-type three-funnelled pheromone-baited trap, so that their free fall to the ECU scanning mechanism and collecting pot of the trap could be ensured. Each group of throws was carried out in two different light conditions – daylight and dark – to determine the effect of ambient conditions of the counting success in the mechanism and to detect whether the energy requirement is satisfied sufficiently in cases where there is no sunshine. External equipment (temperature and humidity data logger and chronometer) was used in order to control the reliability of the parameters recorded on the microSD card.

All statistical analyses were performed using SPSS 20.0 software for Windows®. The differences between the quantitative throwing groups with identified interval scale and counting success in dark and under daylight conditions were checked using the chi-square test. The harmony between the counting success ratio of throwing beetles by groups and counting success ratio of column throwing in the lowest and highest rates were controlled by a binominal test.

Results

In order to evaluate the quantitative success of the prototype trap at pre-determined time intervals, 871 of the 1141 adult beetles were thrown one by one while the remaining 270 were thrown in groups of two, three and four from the funnels of the pheromone-baited trap with ECU. About 87.1% of the total number of beetles was counted

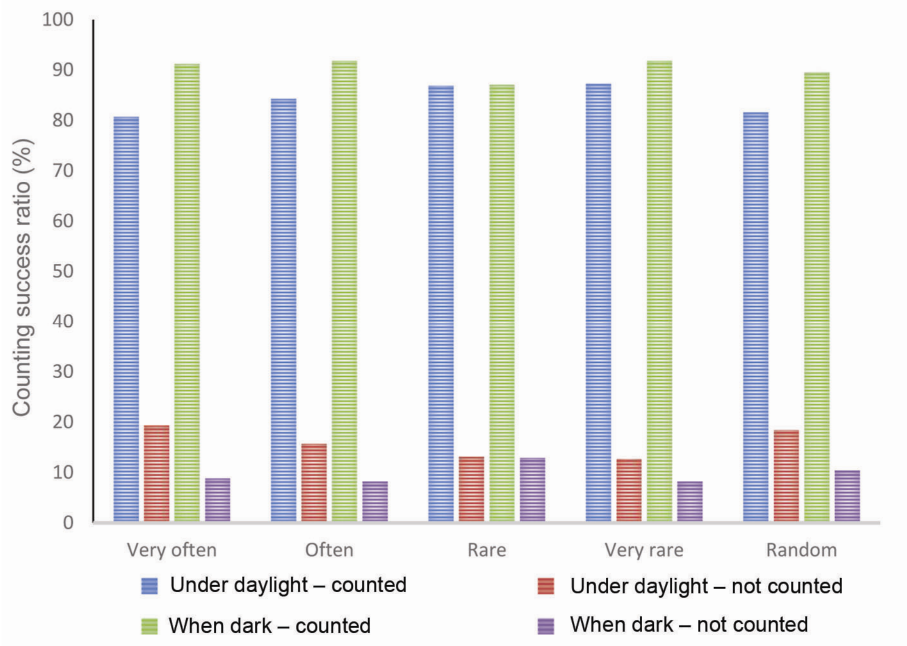

Figure 3. Counting success ratio depending on throwing frequencies under different light conditions of the ECU.

Table 1. Relationship between different light conditions and counting success rates

Light condition	*N*	Counted		Not counted	
		N	Percentage	*N*	Percentage
Daylight	411	344	83.7	67	16.3
Dark	460	415	90.2	45	9.8

$\chi^2 = 8.23$, $df = 1$, $P < 0.05$.

while 12.9% was not counted when they were thrown one by one and evaluated by not taking time interval into account. Instant parameters of the counted beetles were accurately recorded in the CVS format (Figure 2).

In the present study, 83.7% of the 411 beetles thrown in the tests conducted under daylight conditions and 90.2% of the 460 beetles thrown in the tests conducted in dark conditions have been counted and recorded successfully. Even though the counting success ratios of the trap vary in a statistically significant manner ($P < 0.05$) under dark and daylight conditions in the conducted tests, the success ratio of the dark condition tests is only 6.5% higher than the daylight tests (Table 1). From the counting ratios of the designed ECU under dark and daylight conditions, it can be concluded that the ECU will serve the intended aim.

Depending on the throwing frequency with time intervals that have been determined in the study, the success ratios of the 'very often', 'often', 'rare', 'very rare' and 'random' tests are 80.7%, 84.3%, 86.9%, 87.3% and 81.6% respectively under daylight, and 91.2%, 91.8%, 87.1%, 91.8% and 89.6% respectively, under dark conditions (Table 2). There is no statistically significant difference between the counting success ratios of the groups depending on the throwing frequency with pre-determined time intervals in the tests conducted under both dark and daylight conditions ($P > 0.05$) (Table 2).

Moreover, when the performance of the same throwing frequencies of the designed unit is evaluated depending on light differences, there is no statistically significant difference among the counting success ratios of 'very often', 'often', 'rare' and 'very rare' throwing intervals ($P > 0.05$). However, the success ratio of random throws under two different light conditions are found to be statistically different ($\chi^2 = 4.241$, $df = 1$, $P < 0.05$). The reason for the difference in all evaluations may be due to the fact that the random throwing success ratios were statistically different for the two light conditions (Figure 3).

In addition, a total of 270 adult beetles, in groups of 30 each, were thrown simultaneously in groups of two, three and four (Table 3). The counting success ratios in these throwing groups were 86.7%, 83.3% and 83.3% respectively, and the ratios of the incomplete counts, which belong to the throwing groups whose count could not be carried out, were 13.3%, 16.7% and 16.7% respectively. With the possibility of the beetles being caught in the trap at the same time, the designed ECU has been detected to be as sensitive as to take the salicylic difference in the breakage of the laser beams into account. Moreover, the success ratio of the pheromone-baited trap with ECU in counting the beetles thrown simultaneously in groups of two, three, and four does not vary significantly considering its harmony with the lowest counting success of 80.7% and the highest counting success of 91.8% in the

Table 2. Relationship between dark/daylight conditions and throwing frequency groups

		Daylight					Dark			
		Counted		Not counted			Counted		Not counted	
Throwing frequency group	*N*	*N*	Percentage	*N*	Percentage	*N*	*N*	Percentage	*N*	Percentage
Very often	57	46	80.7	11	19.3	57	52	91.2	5	8.8
Often	89	75	84.3	14	15.7	98	90	91.8	8	8.2
Rare	61	53	86.9	8	13.1	62	54	87.1	8	12.9
Very rare	63	55	87.3	8	12.7	61	56	91.8	5	8.2
Random	141	115	81.6	26	18.4	182	163	89.6	19	10.4

$\chi^2 = 1.920$, d$f = 4$, $P > 0.05$.

Table 3. Counting success rate in different throwing groups

		Counted		Not counted*	
Throwing group (number/throwing)	*N* (throw number)	*N*	Percentage	*N*	Percentage
Dual	30	26	86.7	4	13.3
Trio	30	25	83.3	5	16.7
Quart	30	25	83.3	5	16.7

*But, not counting for each beetles, in these throws has been saved as 'Not counted'.

event that the beetles are thrown one by one ($P > 0.05$). The counting performance of the trap does not change when the beetles are captured one by one, or by groups.

Discussion and conclusion

The population density of many bark beetle species in natural habitats has a tendency to increase or decrease depending on weather conditions and well-being of the host[1]. Most abiotic factors have direct or indirect effects on bark beetle populations. Temperature[27], which affects the behaviours, spread, development and reproduction of beetles, is one of the dominant abiotic factors affecting the species directly[28].

It is known that factors such as humidity, wind and light density affect the start of the beetles flight[29] and the change in their sustainability. Bark beetles start flying when the temperature rises above a certain degree (for instance, when temperature is >20°C for the *I. typographus* species[30]) and they soon begin to get caught in the pheromone-baited traps. In the Mediterranean countries and particularly in Turkey's Mediterranean Region, there are some long periods in which the average temperature rises above these degrees (⩽ 20°C) in the spring and summer months. The time of capture of the pest species, into the pheromone-baited traps under dark and under daylight conditions and the temperature and humidity parameters can be simultaneously determined in this study. The time of maximum captures within a day, change in capture ratio, and quantitative assessment of the parameters affecting these captures can be determined using these data. There is no information about how often target species are captured into pheromone-baited traps. The fact that applied evaluations to be carried out with pheromone-baited traps with ECU can express to monitor the populations of beetles has been established with this study as well.

The ECU used in this study cannot differentiate between different species of beetles at present; it only records all the elements that cause laser beam breakage. These captures will be at negligible levels as the number of foreign elements would not be at quantities that could affect counting results significantly. The probability of getting caught in the traps is high for other beetles found in the forests where the traps are effective. However, the number of these captured species is considerably lower than the target species[31]. Depending on the throwing frequencies under dark and daylight conditions, the trap counting success ratios vary between 80.7% and 91.8%. On the other hand, live adult beetles will be the target when the traps are set up in the forests. As the free movement of the beetles at the time of their capture, the larger size of living adult beetles, and the active state of their wingspan when they are falling would increase the breakage ratio of the laser beams, it is expected that the counting success will be higher than that reported in the present study.

The photovoltaic system which is used in the unit, is sufficient for providing the necessary energy to carry out the counting process completely under two different light conditions and to record the parameters. The designed trap with ECU would promote studies related to the ecology and biology of bark beetles, whose monitoring and management are controlled by pheromones. Repeated utilization of this trap, which has a high counting success, in forests will facilitate the quantitative determination of the capture rates of beetles in the different conditions for instance light change, capture frequency, time intervals, etc.

Prevention of bark beetle outbreaks is not possible. So precautions need to be taken against them to decrease the damage caused by the beetles. Pheromone-baited traps with ECU used in this study may be effective in the development of pest management strategies. Thus they will contribute to sustainable forestry policies to minimize the severity of destruction in the forests, and to reduce the economic losses that may occur.

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