



# Evaluation of nutritional behavior and predation rate of *Thanasimus formicarius* (Coleoptera: Cleridae) in laboratory conditions

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## Abstract

Bark beetle is one of the most dangerous groups among forest pests. Periodic outbreaks of these species can cause very serious economic losses as well as negatively affect ecosystem processes and functions. Strategies developed in line with the specific objectives and continued efforts to control these pests are necessary. Environment-friendly and nature compatible methods are preferred to keep the population of pests at low levels. One of the effective methods of suppressing the bark beetle population is biological control. *Thanasimus formicarius*, a general predator of many bark beetle species, is an effective natural enemy of them. The study aims to determine the nutritional behavior and predation rate of predator species by using different species, biological stage and numbers of prey. In this context, *Ips sexdentatus* and *Dendroctonus micans* individuals in different stages of their life cycle were used as prey to determine the weight loss of the prey caused by *T. formicarius*, prey preference, and predation rates of predator beetle. *T. formicarius* adults caused an average weight loss of 0.0188 g of their prey within 24 h. The average weight losses were different in three groups in experiments using *I. sexdentatus* adults alone, *D. micans* larvae alone, and these two species together as prey. In experiments wherein only *I. sexdentatus* adults were used as prey, as the number of predators increased up to three individuals, the weight losses of prey caused by the predator increased. In the evaluations conducted without considering the differences in stages of life cycle and prey species, the predator caught the prey at a rate of 69%. In experiments wherein only *I. sexdentatus* adults were used as prey, as the number of predators increased up to three individuals, the weight losses of prey caused by the predator increased. Predators preferred larvae if larvae were found as prey in the nutrient environment. The average predation rate of *T. formicarius* in experiments using *I. sexdentatus* adults alone as prey was 68.9%, whereas this rate was 71.3% in experiments using *D. micans* larvae alone.

**Keywords** Biological control · Predator beetle · Bark beetle · Weight losses

## Introduction

Forests, which constitute the largest habitat of important plant and animal species and are the most widespread vegetation in the world (Yıldırım and Velioglu 2006; Medhi and Kar 2016), are valuable renewable global resources due to their ecological, social, and economic benefits (Martín-García and Diez

2012). Utilizing forests with sustainable and continuous planning is one of the basic principles of today's forestry (Özcan 2017). However, forests, our natural resources, are adversely affected by many biotic and abiotic factors such as; water, soil, and air pollution; increased industrialization; rapid population growth; climate change; forest fires; pests; and diseases (Forster et al. 2003; Okland and Berryman 2004; Anderegg et al. 2015; Kulakowski 2016; Medhi and Kar 2016; Mehmood et al. 2017; Elburz et al. 2018; Özcan et al. 2018).

The presence and increase in biological invasions affect the biodiversity and ecological integrity of natural ecosystems (Mack et al. 2000). The invasion of insects, causing damage to the forests, is known to cause more losses than other factors (Brockerhoff and Liebhold 2017), and the most destructive species affecting forests are bark beetles (Anderegg et al. 2015; Marini et al. 2017). Biological control, which involves the control of insects and diseases using natural control agents,

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is an environment-friendly, economic, long-term, sustainable, and most promising method that uses beneficial organisms in the nature against harmful organisms (Bailey et al. 2009; Birişik et al. 2014; Uygun et al. 2010; Sanda and Sunusi 2014). Existing natural enemy population can dramatically reduce bark beetle reproduction and population density in infested trees (Weslien and Regnander 1992; Schroeder and Weslien 1994; Biedermann et al. 2019). The suppression of harmful species is possible by increasing the number of predators or pathogens or interspecific competition in the region where the pest is active (Snyder 2019). The density and behavioral ecology of bark beetle species is affected by predators and parasitoid populations (Wermelinger et al. 2012). Accordingly, biological control via the use of predators is an effective control method for regulating harmful insect populations (Eneh 2011).

Predators of different species of bark beetles are usually similar (Reeve et al. 2003). The predators, which have a significant impact on species, especially members of the Cleridae family, are frequently found in the galleries of bark beetles that damage coniferous and deciduous stands (Costello 2003; Koçoğlu and Özcan 2018). *Thanasimus formicarius* (Linnaeus) (Coleoptera: Cleridae), a general predator of many bark beetle species that invades spruce (*Picea* sp.), pine (*Pinus* sp.), and deciduous trees (Warzee and Gregoire 2003), is effective against several of bark beetle species (Akyol and Sarıkaya 2017) and is one of their most abundant natural enemies present in nature (Schroeder 1997).

This predator species is produced in a laboratory environment for the biological control of bark beetle species such as *Ips sexdentatus*, *I. typographus*, and *Pityokteines curvidens* (Coleoptera, Curculionidae, Scolytinae) and released into the forest land in Turkey located in a natural forest belt in terms of forest ecosystems (Akyol and Sarıkaya 2017). In control strategies, predator–insects preferences and predations toward the target species are important. However, it is quite complicated to determine their effectiveness on harmful species because nonspecific predators have a wide range of nutrients in terrain conditions. This study was conducted in the laboratory environment wherein

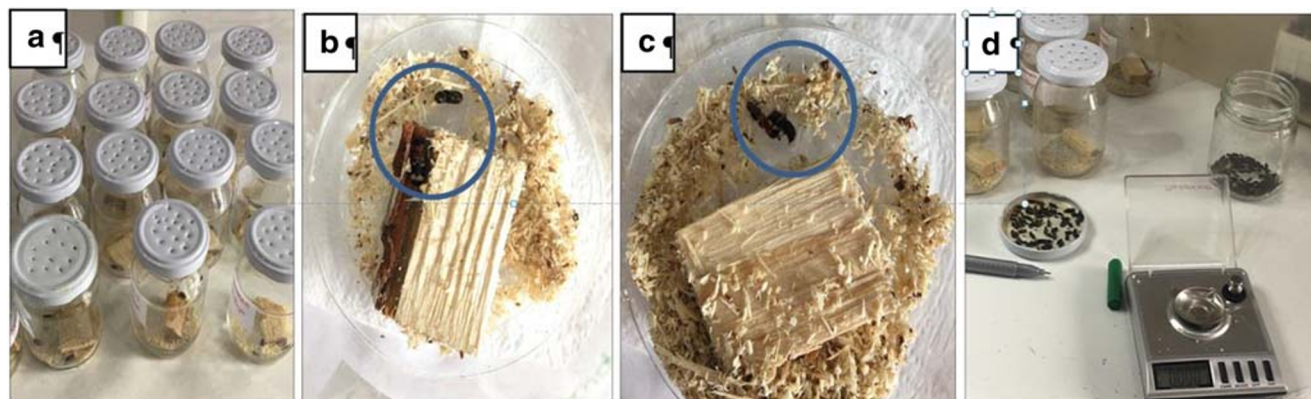
different stages of the life cycle and various *I. sexdentatus* and *Dendroctonus micans* (Coleoptera, Curculionidae, Scolytinae) individuals were used as prey. Consequently, the weight loss of these preys caused by predator insect *T. formicarius*, prey preference, and predation rates of *T. formicarius* were determined.

## Material and method

### Experimental procedure

The study was carried out between May and September 2017 at the Forest Pest Control Laboratory of Kastamonu Forest Regional Directorate. Predator insect *T. formicarius* and its prey *I. sexdentatus* adults used in the experiments were collected from pheromone traps placed in the forests of the region within the scope of biotechnical control. Another prey, *D. micans* larvae, was collected from Artvin oriental spruce forests, which are actively damaged by this pest. *T. formicarius* adults were placed for feeding into glass containers with air inlet holes on the lids (Fig. 1a). Sawdust and a small piece of wood were placed in these containers to ensure moisture balance and to create a habitat for insects (Fig. 1b). An adult *T. formicarius* was placed in each container setup. (Fig. 1c). These containers were placed in the laboratory in a sterile room without light at a temperature of  $21\text{ }^{\circ}\text{C} \pm 1\text{ }^{\circ}\text{C}$  and  $75\% \pm 5\%$  humidity. The individuals of *I. sexdentatus* and *D. micans* in different experiment were used in different numbers and stage of their life cycle as preys. They were weighed twice with a precision scale before and after predator feeding (24 h), and the difference in weight was calculated (Fig. 1d). Predation rates were determined according to the number of prey killed and/or injured by the predator in the experimental setup within the specified period.

A total of 240 experimental setups were designed with 10 different prey groups, each containing five *T. formicarius* individuals, 1200 experiments were carried out (Table 1).



**Fig. 1** Example of experimental setup: **a** Experimental containers with lid holes, **b** *Thanasimus formicarius* and *Ips sexdentatus* adults, **c** The catch of the prey by *Thanasimus formicarius*, **d** Measurement of prey using milligram precision scales

**Table 1** Experimental setups designed according to the prey groups (i.e. variants), and the number of experiments

Variants	Number of <i>I. sexdentatus</i> adults	Number of <i>D. micans</i> larvae	Number of experiments in the group	Number of <i>T. formicarius</i> in the group	Number of total experiments
I.	1	-	48	5	240
II.	2	-	38	5	190
III.	3	-	46	5	230
IV.	4	-	39	5	195
V.	5	-	11	5	55
VI.	6	-	3	5	15
VII.	-	2	25	5	125
VIII.	-	4	7	5	35
IX.	1	1	16	5	80
X.	1	3	7	5	35
Total			240	50	1200

## Data analysis

Data were analyzed using IBM SPSS statistics version 20.0 for Windows® software. Descriptive statistics including variation range, variance, standard deviation, standard error, minimum value, maximum value, and percentages that described the variables in the database were used in the evaluations. The normality of data was checked using Kolmogorov-Smirnov (K-S) single sample test, however, it was found that the data were not normally distributed ( $p < 0.05$ ). In addition, sample size plays an important role in the selection of tests. Since parametric tests are more reliable in large samples ( $n > 30$ ) (Batu 1995; Van Buren and Herring 2020), one-way analysis of variance and independent t-test were used during the analyses. In addition, in the evaluations performed according to the average losses in the prey caused by the predator, the differences between the groups were determined by independent samples t-test and the differences between the averages of more than two groups were determined by one-factor variance analysis. The predation rate that represented the suppression of prey populations was the proportion of prey population that was killed and/or injured (Vucetich et al. 2011). The predation rate was calculated by determining how many preys were killed and/or injured by the predator after 24 h for each experiment and then the value was proportioned to total number of preys.

## Data set

In this study, it was aimed that predators show similar feeding behavior in groups where the predators were fed by the same number of preys. Therefore, the predators were determined in the terms of the difference in the

average weight losses of each prey in the groups eaten by each predator based on the variance analysis. Accordingly, in groups I, II, III, IV, and X, statistically significant differences were found between the average weight losses ( $p < 0.05$ ; Table 2). Predators differing in these groups were determined and all experiments including these predators were excluded, and a total of 1070 experiments were evaluated. In the remaining groups, no significant difference was observed between the averages of weight losses in prey according to the analysis of variance ( $p > 0.05$ ).

## Results

### Weight losses of prey

Of 1070 experiments, in 75% (802) *I. sexdentatus* adults alone, in 15% (160) *D. micans* larvae alone, and in 10% (108) both *I. sexdentatus* adults and *D. micans* larvae were given as prey to *T. formicarius*. When the differences in prey species, different stages of prey life cycle, and prey number were ignored, the average weight loss in the prey that an *T. formicarius* adult caused during the 24-h period was  $0.0188 \pm 0.0141$  g. The average weight loss in experiments using *I. sexdentatus* adults alone as prey (groups I–VI) was  $0.0163 \pm 0.0120$  g;  $0.0274 \pm 0.0179$  g in experiments where *D. micans* larvae alone were used (groups VII–VIII), and  $0.0240 \pm 0.0160$  g in experiments using both prey species (group IX–X; Fig. 2). In these three experimental groups, a significant difference was observed among the average weight losses of prey ( $p < 0.05$ ), and the weight loss amounts in *D. micans* larvae was higher than in *I. sexdentatus* adults.

**Table 2** Results of variance (ANOVA) in terms of average weight loss rates caused by predator according to prey groups

Variants	Number of <i>T. formicarius</i> in the group	Number of experiments	The biological stage of prey	* <i>p</i>
I.	5	48	adult	0.470
II.	5	38	adult	0.004*
III.	5	46	adult	0.006*
IV.	5	39	adult	0.001*
V.	5	11	adult	0.203
VI.	5	3	adult	0.135
VII.	5	25	larvae	0.263
VIII.	5	7	larvae	0.852
IX.	5	16	adult	0.113
X.	5	7	adult	0.025*
			larvae	0.379

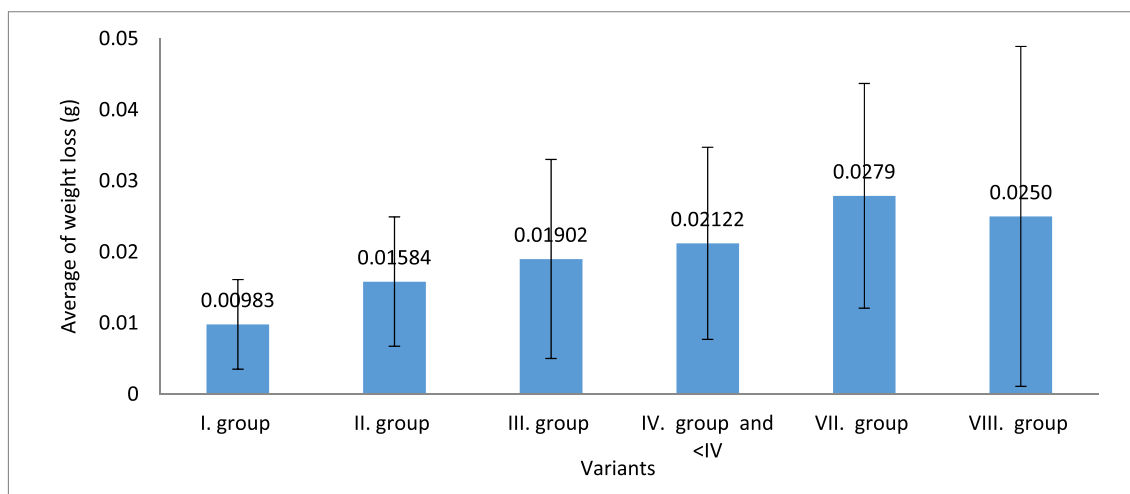
\* $p < 0.05$  refers to different groups

Further, one, two, three, four, five, and six individuals were used as prey in 29.9% (240, group I), 19% (152, group II), 22.9% (184, group III), 19.4% (156, group IV), 6.8% (55, group V), and 1.8% (15, group VI), respectively, in 802 experiments, wherein *I. sexdentatus* adults alone were used as prey. According to the groups, the average amounts of weight losses were 0.00983, 0.01584, 0.01902, 0.01899, 0.02447, and 0.0324 g, respectively. No significant difference was observed between the average weight losses in groups IV, V, and VI ( $p > 0.05$ ). In experiments including four and more *I. sexdentatus* adults, the average weight loss of the prey was 0.02122 g, and the weight loss caused by the predator per day was approximately equal. The weight loss did not increase directly and proportionally with the number of prey.

Besides, according to variance analysis, a significant difference ( $p < 0.05$ ) was observed among the average weight losses in groups I, II, and III. Further, no

significant difference ( $p > 0.05$ ) was observed between the experimental groups using three *I. sexdentatus* adults as prey and the groups using four and more *I. sexdentatus* adults as prey (Fig. 2). As the number of *I. sexdentatus* adults increased, the weight losses caused by the predator increased; further, the difference among the weight losses of the prey with different adult numbers decreased with the increase in the number of adults.

In the 160 experiments, where *D. micans* larvae alone were used as prey, two individuals were used in 78.1% (125, group VII) and four individuals in 21.9% (35, group VIII). The average weight losses caused by *T. formicarius* in the prey were  $0.0279 \pm 0.0158$  and  $0.0250 \pm 0.0239$  g, respectively (Fig. 2). There was a significant difference between the average weights losses in groups VII and VIII according to independent *t*-test ( $p < 0.05$ ).



**Fig. 2** Average weight losses caused by *Thanasimus formicarius* in prey according to prey groups

## Prey preference of the predator

In experiment groups VI and VII, wherein *I. sexdentatus* adults and *D. micans* larvae together were used as prey, a significant difference was observed among the average weight losses in *I. sexdentatus* adults caused by the predator according to independent *t*-test ( $p < 0.05$ ). Moreover, the weight loss in experiments using only *I. sexdentatus* adult was approximately three times higher than the average weight loss in experiments using both *I. sexdentatus* adult and *D. micans* larvae (Fig. 2). This suggests that the predator insect prefers larvae if larvae are found as prey in the nutrient environment. In experimental groups where *I. sexdentatus* adult and *D. micans* larvae were used as prey together, when only *D. micans* larvae were evaluated in terms of weight loss, the average amounts of larval weight loss were statistically different according to the independent *t*-test ( $p < 0.05$ ). The average losses caused by the predator was 0.0274 g in experiments wherein only *D. micans* larvae were used as prey, and the average larval loss was 1.47 times higher in experiments wherein *I. sexdentatus* adults and *D. micans* larvae were used together. This suggests that the predator prefers larvae in the presence of larvae as prey in the environment. With simultaneous use of the *I. sexdentatus* adult and *D. micans* larvae as prey, *T. formicarius* caused 22.8% loss of adults and 77.2% loss of larvae. The amount of loss in experiments using single-prey species was 1.68 times higher for larvae than for adults. In addition, when experiments are setup using both adults and larvae, the predator was primarily oriented toward the larvae.

## Predation rates

In experiments using *I. sexdentatus* adults alone, 100% predation rate was observed in 81.6%, 54%, 31.5%, 20%, 20%, and 6.6% in groups I, II, III, IV, and VI, respectively. As the number of adults used as prey increased, the number of experiments with 100% predation rate decreased. This outcome only differed in group V. In addition, predation rates by groups calculated for half and more of the individuals used as prey were 81.6%, 88.9%, 60.3%, 65.6%, 69%, and 73.5%, respectively (Table 3).

In experiments using *D. micans* larvae alone, the predation rate was a 100% in 70.4% of group VII and 22.9% of group VIII. As the number of larvae used as prey increased, the number of experiments with 100% predation rate decreased. In addition, predation rates by groups calculated for half and more of the individuals used as prey were 96% and 62.9%, respectively. In experiments using two *D. micans* larvae, a 100% predation rate was 3.07 times higher than in experiments using four larvae (Table 4). Although *T. formicarius* adults did not kill all *I. sexdentatus* adults or *D. micans* larvae

**Table 3** Predation rates of *Thanasimus formicarius* on *Ips sexdentatus* adults

Variants	Predation rates (%)	Experiments		
		Number (N)	Percentage (%)	Cumulative (%)
I.	100	196	81.6	81.6
	0	44	18.4	100
II.	100	82	54.0	54.0
	50	53	34.9	88.9
III.	0	17	11.1	100
	100	58	31.5	31.5
IV.	66.7	53	28.8	60.3
	33.3	52	28.3	88.6
V.	0	21	11.4	100
	100	31	19.9	19.9
VI.	75	31	19.9	39.8
	50	40	25.6	65.4
VII.	25	39	25.0	90.4
	0	15	9.6	100
VIII.	100	11	20.0	20.0
	80	16	29.0	49.0
IX.	60	11	20.0	69.0
	40	14	25.4	94.4
X.	20	2	3.6	98.0
	0	1	2.0	100
XI.	100	1	6.6	6.6
	83.3	2	13.3	19.9
XII.	66.7	4	26.8	46.7
	50	4	26.8	73.5
XIII.	33.3	2	13.3	86.8
	16.7	1	6.6	93.4
XIV.	0	1	6.6	100

in which they shared the same environment, they showed sufficient predation to cause the prey population to decrease.

In group IX, in which predation rates were evaluated for *I. sexdentatus* and *D. micans* larvae, which were used as prey together, both adult and larval predation occurred together in 57.5% of experiments, whereas the larval predation rate was 100% in 96.2% of experiments. In group X, both adult and larval predation occurred together in 32.1% of experiments; further, adult predation in 32.1% of experiments and larval predation in 46.4% of the experiments was 100% (Table 5).

In 57.5% experiments in group IX, *I. sexdentatus* adults died. In group X, with the increase in the number of *D. micans* larvae, the adult mortality rate decreased to 32.1%. The predation on *I. sexdentatus* adults decreases due to the increase in the number of *D. micans* larvae as prey. Thus, the predator primarily prefers larvae.

**Table 4** Predation rates of *Thanasimus formicarius* on *Dendroctonus micans* larvae

Variants	Predation rates (%)	Experiments		
		Number (N)	Percentage (%)	Cumulative (%)
IV.	100	88	70.4	70.4
	50	32	25.6	96.0
	0	5	4.0	100
VIII.	100	8	22.9	22.9
	75	3	8.6	31.5
	50	11	31.4	62.9
	25	7	20.0	82.9
	0	6	17.1	100

## Discussion

The activity of natural enemies affects the distribution of harmful species and the change in their populations (Gullan and Cranston 2012; Koçoğlu and Özcan 2018). There is strong evidence that biological control practices using predators and parasitoids are effective in reducing losses caused by many forest pests, such as bark beetles, and support other control strategies (Wermelinger et al. 2012). The ability to locate their prey is a characteristic feature of natural enemies (Raffa et al. 2008), and the predator can locate their prey, even when the prey population is small (Wermelinger et al. 2012). *Thanasimus formicarius*, a potential predator of many species of bark beetles (Warzee and Gregoire 2003), that play an important role in forest ecosystems (Lindgren and Raffa 2013), is one of the most gluttonous predators (Schroeder 1997). Therefore, bark beetles are adversely affected by high predation caused by *T. formicarius* (Costello 2003). In this

study, the average weight losses were different in three groups of experiments using *I. sexdentatus* adults alone, *D. micans* larvae alone, and a combination of two species as prey.

Although *T. formicarius* is a predator that feeds on eggs, larvae, pupa, and the adults of bark beetles (Aksu 2011), the weight loss of *D. micans* larvae is always higher than those in *I. sexdentatus* adults when individuals of different species and in different stages of their life cycle are used as prey. In other words, the predator prefers larvae among the preys in different stages of their life cycle. Clerids found in the galleries feed on both adults and larvae of bark beetles (Wermelinger et al. 2012). Accordingly, many predators can act selectively in their nutritional preferences (Klecka and Boukal 2012). This may vary according to the amount of prey present in the environment and its stage of life a cycle, as shown in the present study. *Thanasimus* species are particularly important predators for *Dendroctonus*, *Ips*, and *Scolytus* (Kenis et al. 2007). Clerid beetles are dominant groups among the natural enemies of scolytids, and they contribute toward the natural control of these pests (Hagen et al. 1999). According to the results of our study, in experiments using *I. sexdentatus* adults as prey alone, as the number of prey increased up to three adults, the prey weight loss caused by the predator insect increased, and the difference among the weight losses of the prey groups with different adult numbers decreased with the increased number of adults. When four or more *I. sexdentatus* adults were used as prey, the prey weight loss did not proportionally increase with the number of prey, and if the prey was given in these numbers, the predator caused a stable loss.

In the present study, predators caught their prey with a predation rate of 69% when the evaluation was carried out without considering the stage of the life cycle of prey and difference in prey species. In laboratory studies on the nutrition behavior of *Thanasimus dubius* (Fab.) (Coleoptera: Cleridae), the predator insect caught its prey with a predation

**Table 5** Predation rates of *Thanasimus formicarius* in experiments where *Ips sexdentatus* adults and *Dendroctonus micans* larvae together were used as prey

Variants	Predation rates (%)		Experiments					
			Number (N)		Percentage (%)		Cumulative (%)	
	Adult <i>I. sexdentatus</i>	Larvae <i>D. micans</i>	Adult <i>I. sexdentatus</i>	Larvae <i>D. micans</i>	Adult <i>I. sexdentatus</i>	Larvae <i>D. micans</i>	Adult <i>I. sexdentatus</i>	Larvae <i>D. micans</i>
IX.	100	100	46	77	57.5	96.2	57.5	96.2
	0	0	34	3	42.5	3.8	100	100
X.	100	100	9	13	32.1	46.4	32.1	46.4
	0	66.7	19	7	67.9	25.0	100	71.4
	-	33.3	-	3	-	10.7	-	82.1
	-	0	-	5	-	17.9	-	100

rate of 72% (Frazier et al. 1981). According to these two studies carried out in laboratory conditions, the predation rates of *T. dubius* and *T. formicarius* have been found to be close to each other and these rates appear to be at levels sufficient to suppress the population levels of pests. Bale et al. (2008) emphasized that natural enemies actively seek their prey and may increase prey control over time.

In our study, the average predation rate of *T. formicarius* in experiments using *I. sexdentatus* adult alone as prey was 68.9%, whereas this rate was 71.3% in experiments using *D. micans* larvae alone. In experiments using a combination of two species as prey, the predation rate of predators on *I. sexdentatus* adults was between 32.1% and 57.5%, whereas this rate was between 66.6% and 96.2% in *D. micans* larvae. When the predation rates were examined, the predator was found to have a greater effect on larvae. In another study where adults and larvae of *I. sexdentatus* were given as prey at the same time, the predation of *T. formicarius* on the larvae was four times more than adults (Koçoğlu and Özcan 2018). Predators and all other natural enemies are effective in the population dynamics of many pests (Reeve 2011), and the predation rates of Clerid insects on various bark beetle species are particularly high (Thatcher and Pickard 1966).

*Thanasimus formicarius*, a predator of *Tomicus piniperda* (Linnaeus) (Coleoptera: Curculionidae: Scolytinae), one of the bark beetle species, decreased the pest population by 81–92%. This rate is high compared to the rate of reduction in reproductive efficiency caused by other predators (Schroeder and Weslien 1994). In addition, Weslien and Regnander (1992) reported that the predation of *T. formicarius* under the bark can also significantly decrease the reproductivity of *I. typographus* and indicated a 45% reduction in pest population based on their experimental studies. Mills (1985) calculated that the survival rate of *I. typographus* larvae in the natural environment decreased from 37–19% with the predation effect of *T. formicarius*. Although they cannot completely prevent the outbreaks of species (Thatcher and Pickard 1966), the positive contribution of natural enemies to biological control practices (Fetting and Hilszczanski 2015) is undeniable considering the predation rates in our study. Although the effect of *T. formicarius* on reducing the reproductive efficiency of *T. piniperda* is higher than the species tested in our study, predation rates are at levels that can cause a reduction in different bark beetle species. In addition, the effect of the predator on *I. typographus* is approximately similar to that observed on *I. sexdentatus* adults.

According to this study, it can be assumed that an *T. formicarius* adult killed or injured approximately three or four *I. sexdentatus* adults or two *D. micans* larvae per day. In laboratory conditions, it has been noted that *T. dubius* (F.) kills on average 2.2 *Dendroctonus frontalis* Zimmerman adults per day (Thatcher and Pickard 1966). Schroder (1997) stated that a *T. formicarius* adult feeds on average three bark beetles per

day and Aksu (2011) stated they feed on 1.5–3 *I. typographus* adults. In addition, Gauss (1954) reported that the number of *I. typographus* consumed by *T. formicarius* daily varies between two and four individuals, whereas Weslien and Regnander (1992) found the average number of *I. typographus* consumed daily to be 0.86 per couple. However, this difference may be due to the limitation of prey (Weslien and Regnander 1992). The number of individuals killed and/or injured by the predator per day is similar to our study.

## Conclusion

The conservation of forests that are affected by various dangers and threats caused by many biotic and abiotic factors is important. Therefore, making harmful factors harmless can only be achieved through protection strategies that are compatible with nature. With this principle, it is important to suppress the bark beetle outbreaks, which cause great damage to the forests. Taking advantage of natural enemies and predators in controlling these species is one of the effective ways, and predators play a critical role in balancing the population of pests in pest management programs. In the present study, *T. formicarius* preferred larvae in experiments using *I. sexdentatus* and *D. micans* in different stages of their life cycle as prey; besides, predation rates on adults and larvae were also quite high. These results show that *T. formicarius*, a general predator, can cause a sufficient reduction of its prey in forests where different species simultaneously cause harm. It is necessary to rear effective predators in the laboratory and release them to the forests to increase the predator density and to keep the balance under control by biological agents.

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## References

- Aksu Y (2011) *Thanasimus formicarius*(L.) (Coleoptera: Cleridae)'ün Biyolojisi, Morfolojisi, laboratuvar şartlarında Üretilmesi ve böcekli sahalara verilmesi. Türkiye 1. Orman Entomolojisi ve Patolojisi Sempozyumu Bildiriler kitabı Kasım, Antalya, pp 86–91
- Akyol A, Sarkaya O (2017) Situation and evaluation of biological and chemical control applications for forest in Turkey. Appl Ecol Environ Res 15(4):341–353. [https://doi.org/10.15666/aecer/1504\\_341353](https://doi.org/10.15666/aecer/1504_341353)
- Anderegg WRL, Hicke JA, Fisher RA, Alle CD, Aukema J, Bentz B, Hood S, Lichstein JW, Macalady AK, McDowell N, Pan Y, Raffa K, Sala A, Shaw JD, Nathan L, Stephenson NL, Tague C, Zeppel M (2015) Tree mortality from drought, insects, and their interactions in a changing climate. New Phytol 208:674–683. <https://doi.org/10.1111/nph.13477>

- Bailey AS, Bertaglia M, Fraser IM, Sharma A, Douarin E (2009) Integrated pest management portfolios in UK arable farming: results of farmers survey. *Pest Manag Sci* 65:1030–1039. <https://doi.org/10.1002/ps.1790>
- Bale JS, Van Lenteren JC, Bigler F (2008) Biological control and sustainable food production. *Philos Trans R Soc Lond B Biol Sci* 363(1492):761–776. <https://doi.org/10.1098/rstb.2007.2182>
- Batu F (1995) Uygulamalı istatistik yöntemler. Karadeniz Teknik Üniversitesi Orm Fak Gen Yay 179(22):312
- Biedermann PH, Müller J, Grégoire JC, Gruppe A, Hage J, Hammerbacher A, Hofstetter RW, Kandasamy D, Kolarik M, Kostovcik M, Krokene P, Sallé A, Six DL, Turini T, Vanderpool D, Wingfield MJ, Bässler C (2019) Bark beetle population dynamics in the Anthropocene: challenges and solutions. *Trends Ecol Evol* 34(10):914–924. <https://doi.org/10.1016/j.tree.2019.06.002>
- Birişik N, Küçük H, Karacaoğlu M, Yarpuzlu F, İslamoğlu M, Öztemiz S (2014) Teoriden pratiğe biyolojik mücadele. T.C. Gıda Tarım ve Hayvancılık Bakanlığı Gıda ve Kontrol Genel Müdürlüğü, Ankara
- Brockerhoff EG, Liebhold AM (2017) Ecology of forest insect invasions. *Biol Invasions* 19(11):3141–3159. <https://doi.org/10.1007/s10530-017-1514-1>
- Costello S (2003) Clerid beetles-voracious predators PDF. Colorado State University Department of Entomology, Fort Collins, pp 1–15
- Elburz Z, Çubukçu KM, Nijkamp P (2018) The mutual relationship between regional income and deforestation. *Metu Jfa* 35(2):77–87. <https://doi.org/10.4305/METU.JFA.2018.2.4>
- Eneh OC (2011) Enhancing Africa's environmental management: integrated pest management for minimizing of agricultural pesticides pollution. *Res J Environ Sci* 5:521–529. <https://doi.org/10.3923/rjes2011521529>
- Fettig CJ, Hilszczanski J (2015) Management strategies for bark beetles in conifer forests. In bark beetles.. Academic, Amsterdam, pp 555–584 <https://doi.org/10.1016/B978-0-12-417156-5.00014-9>
- Forster B, Meier F, Gall R (2003) Bark beetle management after a mass attack - some Swiss experiences. In: McManus, ML, Liebhold, AM (eds) Proceedings: ecology, survey and management of forest insects; 2002 September 1–5; Krakow, Poland. Gen. Tech. Rep. NE-311. U.S. Dept. of Agriculture, Forest Service, Northeastern Research Station, Newtown Square, pp 10–15
- Frazier JL, Nebeker TE, Mizell RF, Calvert WH (1981) Predatory behavior of the clerid beetle *Thanasimus dubius* (Coleoptera: Cleridae) on the southern pine beetle (Coleoptera: Scolytidae). *Can Entomol* 113(1):35–43
- Gauss R (1954) Die ameisenbuntkäfer, *Thanasimus* (Clerus) *formicarius* Latr. als borkenkäferfeind. In: Wellenstein G (ed) Die große Borkenkäferkalamität in Südwes-Deutschland 1944–1951. Wellenstein, Ringingen/Wiittental, pp 417–429
- Gullan PJ, Cranston PS (2012) The insect an outline of entomology, 4th edn. Wiley-Blackwell, Hoboken, XVI + 564
- Hagen KS, Mills NG, Gordh G, McMurtry JA (1999) Terrestrial arthropod predators of insect and mite pests. In: Bellows TS, Fisher TW (eds) Handbook of biological control: principles and applications of biological control. Academic, San Diego, pp 383–503
- Kenis M, Wermelinger B, Grégoire JC (2007) Research on parasitoids and predators of Scolytidae—a review. In: InnBark and wood boring insects in living trees in Europe, a synthesis. Springer, Dordrecht, pp 237–290
- Klecka J, Boukal DS (2012) Who eats whom in a pool? A comparative study of prey selectivity by predatory aquatic insects. *PLoS One* 7(6):e37741. <https://doi.org/10.1371/journal.pone.0037741>
- Koçoğlu N, Özcan GE (2018) Feeding preferences of the rearing of *Thanasimus formicarius* (L.) (Coleoptera, Cleridae). *Alinteri J Agric Sci* 33(2):215–220. <https://doi.org/10.28955/alinterizbd.449574>
- Kulakowski D (2016) Managing bark beetle outbreaks (*Ips typographus*, *Dendroctonus spp.*) in conservation areas in the 21st century. *For Res Pap* 77(4):352–357. <https://doi.org/10.1515/frp-2016-0036>
- Lingren BS, Raffa KF (2013) Evolution of tree killing in bark beetles (Coleoptera: Curculionidae): trade-offs between the maddening crowds and a sticky situation. *Can Entomol* 145(5):471–495. <https://doi.org/10.4039/tce.2013.27>
- Mack RN, Simberloff D, Lonsdale EM, Evans H, Clout M, Bazzaz FA (2000) Biotic invasions: causes, epidemiology, global consequences and control. *Ecol Appl* 10(3):689–710. <https://doi.org/10.2307/2641039>
- Marini L, Økland B, Jönsson AM, Bentz B, Carroll A, Forster B, Grégoire JC, Hurling R, Nageleisen LM, Netherer S, Ravn HP, Weed A, Schroeder M (2017) Climate drivers of bark beetle outbreak dynamics in Norway spruce forests. *Ecography* 40:001–010. <https://doi.org/10.1111/ecog.02769>
- Martín-García J, Diez JJ (2012) Sustainable forest management: an introduction and overview, sustainable forest management - current research, Diez JJ (ed), ISBN: 978-953-51-0621-0, InTech, Available from: <http://www.intechopen.com/books/sustainable-forest-management-currentresearch/sustainable-forest-management-an-introduction-and-overview>. Accessed 13 May 2019
- Medhi D, Kar BK (2016) Depletion of forest cover and encroachment in Gonbina Reserved Forest in Goalpara district of Assam. *Space Culture India* 4(1):40–50. <https://doi.org/10.20896/saci.v4i1.187>
- Mehmood M, Yaseen M, Ud-Din I, Badshah A, Khan MJ, Haroon (2017) Causes of deforestation and its geological impacts in Swat District, Khyber Pakhtunkhwa, Pakistan. *Asian J Environ Eco* 5(4):1–9
- Mills NJ (1985) Some observations on the role of predation in the natural regulation of *Ips typographus* populations I. *Ztschr f Angew Ent* 99(1-5):209–215
- Okland B, Berryman A (2004) Resource dynamic plays a key role in regional fluctuations of the spruce bark beetles *Ips typographus*. *Agric For Entomol* 6:141–146. <https://doi.org/10.1111/j.1461-9555.2004.00214.x>
- Özcan GE (2017) Assessment of *Ips sexdentatus* population considering the capture in pheromone traps and their damages under non-epidemic conditions. *Şumar List* 141(1–2):47–55
- Özcan GE, Aydın M, Enez K (2018) Bark beetle outbreaks in forest due to climate change. International Conference on Science and Technology. ICONST. Prizren, Kosova
- Raffa KF, Aukema BH, Bentz BJ, Carroll AL, Hicke JA, Turner MG, Romme WH (2008) Crossscale drivers of natural disturbances prone to anthropogenic amplification: the dynamics of bark beetle eruptions. *Bioscience* 58:501–517. <https://doi.org/10.1641/B580607>
- Reeve JD (2011) Predators of the southern pine beetle. In: Coulson, RN; Klepzig, KD 2011. Southern Pine Beetle II. Gen. Tech. Rep. SRS-140. US Department of Agriculture Forest Service, Southern Research Station, Asheville 140:153–160
- Reeve JD, Rojas MG, Morales-Ramos JA (2003) Artificial diet and rearing methods for *Thanasimus dubius* (Coleoptera: Cleridae), a predator of bark beetles (Coleoptera: Scolytidae). *Biol Control* 27 (3): 315–322. [https://doi.org/10.1016/S1049-9644\(03\)00021-5](https://doi.org/10.1016/S1049-9644(03)00021-5)
- Sanda NB, Sunusi M (2014) Fundamentals of biological control of pests. *Int J Chem Bio Sci* 1(6):1–11. <https://doi.org/10.13140/RG.2.2.19011.20002>
- Schroeder LM (1997) Impact of natural enemies on *Tomicus piniperda* offspring production. Proceedings: Integrating cultural tactics into the management of bark beetle and reforestation pests. USDA Forest Service General Technical Report 236: 204–214
- Schroeder LM, Weslien J (1994) Interactions between the phloem-feeding species *Tomicus piniperda* (Col.: Scolytidae) and *Acanthocinus aedilis* (Col.: Cerambycidae) and the predator *Thanasimus formicarius* (Col.: Cleridae) with special reference to brood production. *Entomophaga* 39:149–157

- Snyder WE (2019) Give predators a complement: conserving natural enemy biodiversity to improve biocontrol. *Biol Control* 135:73–82. <https://doi.org/10.1016/j.biocontrol.2019.04.017>
- Thatcher RC, Pickard LS (1966) The clerid beetle, *Thanasimus dubius*, as a predator of the southern pine beetle. *J Econ Entomol* 59(4):955–957
- Uygun N, Ulusoy MR, Satar S (2010) Biyolojik mücadele. *Türkiye Biyol Mücadele Derg* 1(1):1–14
- Van Buren E, Herring AH (2020) To be parametric or non-parametric, that is the question: Parametric and non-parametric statistical tests. *BJOG* 127(5):549–550. <https://doi.org/10.1111/1471-0528.15545>
- Vucetich JA, Hebblewhite M, Smith DW, Peterson RO (2011) Predicting prey population dynamics from kill rate, predation rate and predator–prey ratios in three wolf ungulate systems. *J Anim Ecol* 80(6):1236–1245
- Warzee N, Grégoire JC (2003) *Thanasimus formicarius* (Coleoptera, Cleridae) Why a large range of prey for a specialized predator? Proceedings. IUFRO Kanazawa, Forest insect population dynamics and host influences 16–18
- Wermelinger B, Epper C, Kenis M, Ghosh S, Holdenrieder O (2012) Emergence patterns of univoltine and bivoltine *Ips typographus* (L.) populations and associated natural enemies. *J Appl Entomol* 136(3):212–224. <https://doi.org/10.1111/j.1439-0418.2011.01629.x>
- Weslien J, Regnander J (1992) The influence of natural enemies on brood production in *Ips typographus* (Col. Scolytidae) with special reference to egg-laying and predation by *Thanasimus formicarius* (Col.: Cleridae). *Entomophaga* 37(2):333–342
- Yıldırım HT, Veliöğlu N (2006) Sürdürülebilir orman yönetiminde ölçüt ve göstergelerin incelenmesi. *İÜ Orm Fak Derg* 56(1):129–140

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