

Coleopterous predators of pine bark beetles in the last years of the outbreak recorded in Ukraine

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ABSTRACT

The purpose of this study was to identify the species composition of coleopterous predators and their occurrence in different parts of the stem depending on the health condition of Scots pine (*Pinus sylvestris* L.) in the collapsing foci of bark beetles (Coleoptera: Curculionidae: Scolytinae). The research was carried out in 2019–2021 at 38 sample plots located in five State Forestry Enterprises of Sumy region (Ukraine). All sample plots are located in pure Scots pine stands in relatively poor forest site conditions. The relative density of stocking is 0.6–0.7, and the age of stands is between 60 and 110 years. The health condition for each tree was evaluated on visual characteristics by the classes: first – healthy; second – weakened; third – severely weakened; fourth – drying up; fifth – recently died and sixth – died over a year ago. Bark beetles’ nuptial chambers and predators were counted on 25 × 25 cm pallets, which were located at the lower, middle and upper parts of the stem with thin, thick and transitional bark, respectively. The significance of differences in the performance of predator species depending on the tree part, health condition and year was analysed using the nonparametric Kruskal–Wallis (K–W) test. The species composition of predators in different years, stem parts and tree health condition was compared using the Sorensen–Chekanovsky index.

In the collapsing foci of bark beetles, the health condition of Scots pine in 2019–2021 tended to worsen. The infestation density of *Ips acuminatus* (Gyllenhal, 1827) and *Ips sexdentatus* (Boerner, 1767) was 0.62 ± 0.032 and 0.64 ± 0.017 nuptial chambers per 1 dm², respectively, and also decreased in 2019–2021. In the galleries of bark beetles, seven species of coleopterous predators were collected: *Aulonium ruficorne* (Olivier, 1790) (Zopheridae), *Platysoma elongatum* (Leach, 1817) (Histeridae), *Rhizophagus depressus* (Fabricius, 1792) (Monotomidae), *Corticium pini* (Panzer, 1799) (Tenebrionidae), *Thanasimus formicarius* (Linnaeus, 1758), *Thanasimus femoralis* (Zetterstedt, 1828) (Cleridae) and *Salpingus ruficollis* (Linnaeus, 1761) (Salpingidae). Two more species – *Glischrochilus quadripunctatus* (Linnaeus, 1758) (Nitidulidae) and *Pytho depressus* (Linnaeus, 1767) (Pythidae) – were singly collected in the foci. *T. formicarius* and *P. elongatum* were the most abundant. The ratio of predator–prey significantly increased from the upper to the lower part of the stem with thick bark. It, however, decreased in this stem part from the fourth to the sixth class of the health condition of the host tree.

KEY WORDS

Pinus sylvestris forest, Sumy region of Ukraine, frequency of occurrence, health condition class, nuptial chambers, predator/prey ratios

INTRODUCTION

The decline of forests has occurred in the last decade in many regions of Europe (Colombari et al. 2013; Andreieva and Goychuk 2018; Andreieva et al. 2019). Drought and increasing anthropogenic impact led to an increase in the susceptibility of trees to colonisation by bark beetles, among which the multivoltine species *Ips acuminatus* (Gyllenhal, 1827) and *Ips sexdentatus* (Boerner, 1767) (Coleoptera: Curculionidae: Scolytinae) gained an advantage in a pine forest (Meshkova 2019, 2021; Wermelinger et al. 2021). In the Sumy region of Ukraine, an outbreak of bark beetles in Scots pine stands started after a drought in 2015 (Meshkova and Bobrov 2020; Meshkova et al. 2021). The highest population density of these bark beetles was registered in 2017, and then their population began to collapse (Meshkova 2021).

So far, the main way to reduce the consequences of outbreaks of bark beetles remains selective or clear sanitary felling (Anonymous 2016). However, it can be effective only if it is carried out after the colonisation of trees by bark beetles, but before the emergence of a new generation (Meshkova 2019). Removing dead trees is not useful since bark beetles that are dangerous to living trees do not colonise dead trees (Selikhovkin 2017). This action is even harmful since entomophages and saproxylic insects concentrate under the bark of dead trees (Sanginés de Cárcer et al. 2021).

Numerous studies show that entomophages (parasitoids and predators) can significantly reduce the populations of bark beetles (Herard and Mercadier 1996; Sarikaya and Avci 2009; Fora et al. 2012; Yaman et al. 2016; Cebeci and Baydemir 2018; Akkuzu et al. 2021). However, usually, during the outbreaks of bark beetles, the populations of predators increase later than those of prey (Kenis et al. 2004). In order to accelerate the collapse of bark beetles' population, certain species of predatory insects are reared in the laboratory and released into the forest (Kharitonova 1972; Kenis et al. 2004). When choosing a predator species for rearing, it is important to study its habitats, seasonal development, hibernation sites

and other biological features (Kenis et al. 2004). Preference is given to polyphagous species that attack various stages of prey, have high fecundity, are able to develop without diapause, reproduce over a long period and have several generations per year. These conditions are satisfied by several species of coleopterous predators, which are reared and successfully released into the foci of bark beetles, particularly, *Thanasimus formicarius* (Linnaeus, 1758) (Cleridae), *Aulonium ruficorne* (Olivier, 1790) (Zopheridae) and *Rhizophagus grandis* Gyll., 1827 (Monotomidae) (Zondag 1979; Kereselidze et al. 2010; Podoler et al. 1990; Özcan et al. 2021; Özcan and Koçoğlu 2021).

In 2018–2019, the State Specialized Forest Protection Enterprise 'Kharkivlisozahyst' (Kharkiv region, Ukraine) began rearing *T. formicarius* and releasing it into foci of bark beetles. The more rapid collapse of bark beetle outbreak as compared to the control was registered for the plots with predator release (Meshkova et al. 2021). However, many issues related to the distribution and development of coleopterous predators remain poorly understood, in particular, in the northeastern regions of Ukraine, where the population of bark beetles is collapsing.

The purpose of this research was to recognise the species composition of coleopterous predators of bark beetles and their occurrence in different parts of the stem depending on the health condition of Scots pine trees in the collapsing foci of bark beetles.

MATERIAL AND METHODS

The research was carried out in 2019–2021 in the foci of Scots pine (*Pinus sylvestris* L.) decline at 38 sample plots located in five State Forestry Enterprises of Sumy region (Ukraine) (Tab. 1). Svessky and Seredyno-Budsky Forestry Enterprises are in the northern part of Sumy region (Forest zone, or Polissya). Krolevetsky, Lebedinsky and Trostyanetsky Forestry Enterprises are in the southern part of Sumy region (Forest-steppe zone). In the forest and forest-steppe parts of Sumy region, the annual

Table 1. Location of inspected forest stands

State Forestry Enterprise	Forestry	Latitude, N	Longitude, E	Altitude, m a.s.l.	Number of plots	Number of gallery systems
Svessky	Prudishchenske	51°57'17¢	33°43'38¢	159	3	54
Svessky	Olynske	51°56'51¢	33°47'15¢	165	6	110
Seredyno-Budsky	Kamyanske	52°05'49¢	33°53'06¢	196	2	36
Seredyno-Budsky	Golubivske	50°48'01¢	34°25'10¢	170	6	110
Seredyno-Budsky	Ochkinske	52°13'36¢	33°22'41¢	130	2	36
Krolevetsky	Dubovytske	51°38'05¢	33°34'21¢	162	7	126
Krolevetsky	Gruzchanske	51°12'32¢	33°31'45¢	158	4	72
Krolevetsky	Krolevetske	51°33'10¢	33°22'57¢	166	1	18
Krolevetsky	Khreshchatynske	51°38'23¢	33°22'07¢	154	1	18
Lebedinsky	Mezhyrichske	50°41'58¢	34°29'39¢	145	1	18
Lebedinsky	Borovenkivske	50°27'52¢	34°24'32¢	142	1	18
Lebedinsky	Ukrainske	50°29'28¢	34°30'23¢	140	1	18
Trostryanetsky	Makivske	50°53'10¢	34°97'15¢	165	1	18
Trostryanetsky	Lytovske	50°36'15¢	34°86'12¢	143	1	18
Trostryanetsky	Trostryanetske	50°28'30¢	34°58'18¢	118	1	18
Total					38	688

air temperature is 6.6°C and 5.7°C, the duration of the vegetation period is 185 and 196 days, and annual precipitation is 894 and 535 mm, respectively (Ostapenko and Vorobyov 2014).

All sample plots are located in pure Scots pine stands in relatively poor forest site conditions – B₂ (Ostapenko and Vorobyov 2014). The relative density of stocking is 0.6–0.7, and the age of stands is between 60 and 110 years.

Considering that the population level of bark beetles and their predators depends on the number of trees susceptible to colonisation, the health condition class of each sample tree was assessed.

The health condition for each tree was evaluated on a range of visual characteristics according to the 'Sanitary Forest Regulations in Ukraine' (Anonymous 1995) and was divided into the following classes: first – healthy; second – weakened; third – severely weakened; fourth – drying up; fifth – recently died and sixth – died over a year ago. The health condition index (HCI) was calculated as a weighted average of the trees in each class of health condition. Sample plots were taken for analysis, where the health condition of trees did not differ significantly (Kruskal–Wallis [K–W] test: $H = 2.74, p = 0.2537$).

Bark beetles' nuptial chambers and predators were counted on 25 × 25 cm pallets, which were located at the parts of the stem with thin, thick and transitional bark. Bark thickness at the lower part of Scots pine stems was over 2 cm, in the upper part was below 0.3 cm and the width of transitional bark in the middle part of the stem was 0.5–0.8 cm. For this research, the number of nuptial chambers of bark beetles was recalculated on 1 dm².

The prevalence of predator species in different complexes was assessed on a scale: single – up to 0.1% of the total, rare – 0.1–1%, common – 1–5% and abundant – more than 5% (Bieliavtsev and Skrylnik 2020).

To analyse the performance of different predator species depending on the tree part, health condition and year, normality tests were performed. The significance of differences in studied traits was analysed using the nonparametric K–W test because the conditions of normality were not met. When the differences were significant, the Dunn procedure for multiple pairwise comparisons was applied.

The species composition of predators in different sample plots was compared using the Sorensen–Chekanovskiy index (1) (Leontyev 2008):

$$C_{sc} = \frac{2c}{a+b} \quad (1)$$

where:

- a* – the number of predator species in the first sample,
- b* – the number of predator species in the second sample,
- c* – the number of predator species common to both samples.

Microsoft Excel software and statistical software package Paleontological Statistics (PAST) Software Package for Education and Data Analysis (Hammer et al. 2001) were used.

RESULTS

In the inspected foci of bark beetles, most pine trees were characterised by the third to sixth classes of health condition. However, the bark beetles and their predators were found in the trees in the fourth to sixth classes of health condition.

The health condition of the examined trees tended to worsen (increase in the HCI) during 2019–2021 (K–W test: $H = 61.65$ – 149.1 for different pairs of groups, $p < 0.0001$). Differences between the HCI of trees, on which samples were taken from sections of the stem with thin and transitional bark, were not significant (K–W test: $H = 0.66$, $p = 0.71$) (Tab. 2).

Two bark beetle species, *I. acuminatus* and *I. sexdentatus*, were presented at sample trees. *I. acuminatus* colonised the parts of the stem with thin bark, and *I. sexdentatus* colonised the parts of the stem with

thick bark. Both the bark beetle species were found at the stem parts with transitional bark.

In all foci, the population of bark beetles was collapsing. The average (\pm standard error) infestation density (number of nuptial chambers per 1 dm²) calculated from all samples collected was 0.66 ± 0.27 , 0.47 ± 0.18 and 0.42 ± 0.23 in 2019, 2020 and 2021, respectively.

Infestation density (number of nuptial chambers per 1 dm²) calculated from all 1443 samples collected was 0–2.72 for *I. acuminatus* (0.62 ± 0.032) ($n = 252$ samples) and 0–2.40 for *I. sexdentatus* (0.64 ± 0.017) ($n = 945$ samples). Infestation density for samples in the transition bark with the presence of both species was 0–3.04 (0.54 ± 0.034) ($n = 246$ samples) (Fig. 1).

At the same time, the coefficient of variation of this parameter was quite high (81.7% and 80% for *I. acuminatus* and *I. sexdentatus*, respectively), and for settlements of both species in the samples with transitional bark, it was 99.4%.

No significant differences were found in the colonisation of the upper and lower parts of the stem by the two bark beetle species (K–W test: $H = 2.74$, $p = 0.25$) (Fig. 1).

Nine species of coleopterous predators were found in the analysed trees. In the galleries of bark beetles, seven species coleopterous predators were collected: *A. ruficornis* (Olivier, 1790) (Zopheridae), *Platysoma elongatum* (Leach, 1817) (Histeridae), *Rhizophagus depressus* (Fabricius, 1792) (Monotomidae), *Corticeus pini* (Panzer, 1799) (Tenebrionidae), *Th. formicarius* (Linnaeus, 1758), *Thanasimus femoralis* (Zetterstedt, 1828) (Cleridae) and *Salpingus ruficollis* (Linnaeus, 1761) (Salpingidae).

Two more species – *Glischrochilus quadripunctatus* (Linnaeus, 1758) (Nitidulidae) and *Pytho depressus* (Linnaeus, 1767) (Pythidae) – were singly collected in the foci, but the confinement to the categories of tree health condition and stem parts could not be determined. Therefore, these species were not considered in the data processing.

T. formicarius (44.4%) and *P. elongatum* (40.7%) took the leading places in terms of the proportion of infested samples (Fig. 2). More than 30% of the samples contained *R. depressus*, *A. ruficornis* and *C. pini*. Less common was *T. femoralis* and *S. ruficollis* was the rarest.

Table 2. HCI for Scots pine trees sampled in different stem parts

Sampled part of stem	Mean HCI \pm st. err. for years*		
	2019	2020	2021
Upper (thin bark)	4.4 \pm 0.13a (27)	5.3 \pm 0.07b (72)	6.0 \pm 0.0c (30)
Middle (transitional bark)	4.4 \pm 0.13a (27)	5.3 \pm 0.07b (72)	6.0 \pm 0.0c (30)
Lower (thick bark)	4.5 \pm 0.08a (72)	4.7 \pm 0.04d (265)	5.3 \pm 0.05e (90)
All samples	4.5 \pm 0.06a (126)	4.9 \pm 0.04f (409)	5.6 \pm 0.04g (150)

Note: * Number of trees in parentheses. Means followed by different letters are significantly different at the 95% confidence level. HCI – health condition index.

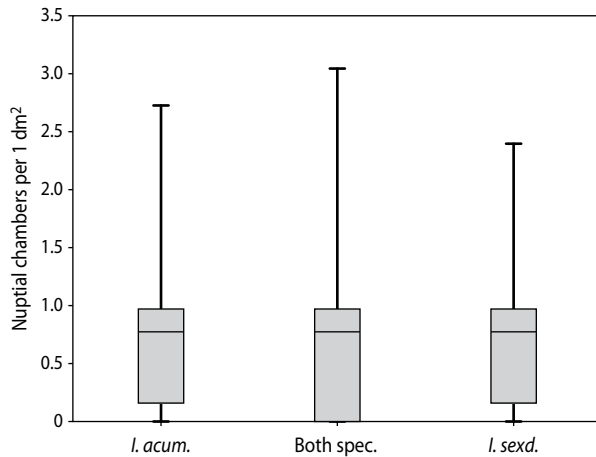


Figure 1. Population density of bark beetles in sample trees as the number of nuptial chambers per 1 dm² of Scots pine bark sample (*I. acum.* – *Ips acuminatus*; *I. sexd.* – *Ips sexdentatus*; both spec. – both species; boxes – standard error, bars – minimum–maximum)

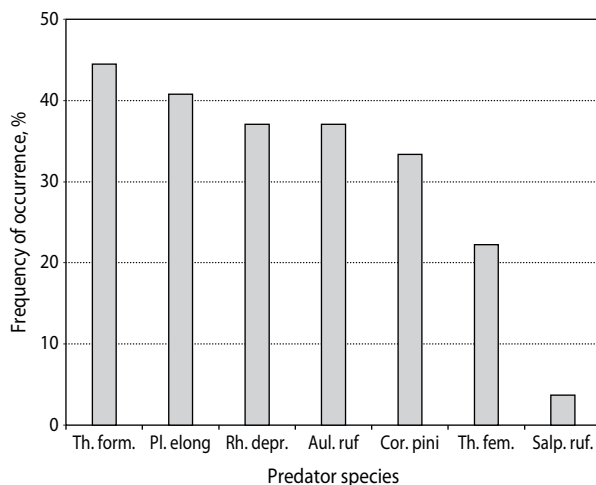


Figure 2. Mean frequency of occurrence of coleopterous predators in the bark samples (*Th. form.* – *Thanasimus formicarius*; *Pl. elong.* – *Platysoma elongatum*; *Rh. depr.* – *Rhizophagus depressus*; *Aul. ruf.* – *Aulonium ruficorne*; *Cor. pini* – *Corticeus pini*; *Th. fem.* – *Thanasimus femoralis*; *Salp. ruf.* – *Salpingus ruficollis*)

The distribution of predators on different parts of the stem differed significantly (K–W test: $H = 9.45$, $p = 0.009$).

The Sorensen–Chekanovsky index (C_{sc}) showed different similarities of predator species composition

between stem parts, class of tree health condition and years.

For all years and classes of the tree health condition, the similarity between upper and lower parts of the stem was the lowest ($C_{sc} = 0.83$) and the similarity between the predator species composition in the trees of the fifth and sixth classes of health condition as well as between 2019 and 2021 was the highest ($C_{sc} = 1.0$) (Tab. 3).

If we specify the location of the bark samples and the class of tree health condition, then the values of the Sorensen–Chekanovsky index ($C_{sc} = 0.57$) are minimal when comparing the samples from the upper part of trees of the sixth class during the surveys of 2020 and the middle and lower parts of the same trees. Predator complexes in the middle and lower parts of trees of the fifth and sixth classes of the health condition in 2020 were of high similarity ($C_{sc} = 0.80$). A similar Sorensen–Chekanovsky index was calculated at the 2021 assessment in trees of the sixth class of the health condition for the samples from the upper and middle parts of the stem. The highest similarity of predator complexes was found between the samples from the lower and middle parts of trees of the sixth class of health condition in 2021.

The proportion of the number of individual predator species and bark beetles depended on the year of assessment, tree health condition (Tab. 4) and stem part (Tab. 5).

Predators were not found in the samples with thin and transitional bark from the trees of the fourth class of health condition (Tab. 4).

In the lower part of the stem, seven predator species were found with the dominance of *A. ruficorne* (40.8%). Five more species can be considered abundant, and *S. ruficollis* was common. On trees of the fifth and sixth classes of health condition, three and four predator species, respectively, were found in the upper part of the stem, and all of them were abundant. However, *P. elongatum* was found in the upper part of the trees only of the sixth class of health condition, while *T. formicarius* was found only in the upper parts of the trees of the fifth class of health condition.

In the transition bark of the trees of the fifth and sixth health condition classes, four and six predator species were found, respectively. *C. pini* dominated in the trees of the fifth class of the health condition; however, the remaining three predator species were also abun-

Table 3. Calculation of Sorenson–Chekanovsky index (C_{sc}) for predator complexes in the different parts of stem, class of tree health condition and years of assessment

Group of samples A			Species number in A	Group of samples B			Species number in B	Number of common species for A and B	C_{sc}
HCC	Stem part	Year		HCC	Stem part	Year			
All	U	All	5	All	L	All	7	5	0.83
All	U	All	5	All	M	All	6	5	0.91
All	M	All	6	All	L	All	7	6	0.92
4	All	All	7	5	All	All	6	6	0.92
4	All	All	7	6	All	All	6	6	0.92
5	All	All	6	6	All	All	6	6	1.00
All	All	2019	6	All	All	2020	7	6	0.92
All	All	2019	6	All	All	2021	6	6	1.00
All	All	2020	7	All	All	2021	6	6	0.92
5	U	2020	3	5	M	2020	4	2	0.57
5	U	2020	3	5	L	2020	6	3	0.67
5	M	2020	4	5	L	2020	6	4	0.80
6	U	2020	2	6	M	2020	5	2	0.57
6	U	2020	2	6	L	2020	5	2	0.57
6	M	2020	5	6	L	2020	5	4	0.80
6	U	2021	4	6	M	2021	6	4	0.80
6	U	2021	4	6	L	2021	5	4	0.89
6	M	2021	6	6	L	2021	5	5	0.91

Note: The groups of sample plots without predators are not considered. HCC – health condition class of the trees. Stem part – U – upper; M – middle; L – lower

Table 4. Species composition of coleopterous predators in sample trees of different health condition

Predator species	Health condition classes		
	4 – drying up	5 – recently died	6 – died over a year ago
1	2	3	4
Upper stem part (thin bark)			
<i>Corticeus pini</i>	0	58.4 ± 14.23a	15.6 ± 6.41b
<i>Rhizophagus depressus</i>	0	0	34.4 ± 8.40c
<i>Platysoma elongatum</i>	0	33.3 ± 13.60c	21.9 ± 7.31c
<i>Aulonium ruficorne</i>	0	0	28.1 ± 7.95d
<i>Thanasimus formicarius</i>	0	8.3 ± 7.96e	0
Middle stem part (transitional bark)			
<i>Corticeus pini</i>	0	45.5 ± 10.62a	7.3 ± 3.50b
<i>Rhizophagus depressus</i>	0	22.7 ± 8.93c	18.2 ± 5.20c
<i>Platysoma elongatum</i>	0	0.0	20.0 ± 5.39c
<i>Aulonium ruficorne</i>	0	13.6 ± 7.32d	25.5 ± 5.87d

1	2	3	4
<i>Thanasimus formicarius</i>	0	18.2 ± 8.22d	25.5 ± 5.87d
<i>Thanasimus femoralis</i>	0	0.0	3.6 ± 2.52e
Lower stem part (thick bark)			
<i>Corticeus pini</i>	15.3 ± 3.64a	20.0 ± 2.67a	4.7 ± 3.21e
<i>Rhizophagus depressus</i>	13.3 ± 3.43a	18.7 ± 2.60a	11.6 ± 4.89a
<i>Platysoma elongatum</i>	9.2 ± 2.92a	15.6 ± 2.42a	9.3 ± 4.43a
<i>Aulonium ruficorne</i>	40.8 ± 4.96b	28.0 ± 2.99c	58.1 ± 7.52b
<i>Salpingus ruficollis</i>	2.0 ± 1.43d	0.0d	0.0d
<i>Thanasimus formicarius</i>	14.3 ± 3.53a	13.3 ± 2.27a	4.7 ± 3.21e
<i>Thanasimus femoralis</i>	5.1 ± 2.22d	4.4 ± 1.37d	11.6 ± 4.89d

Note: Means followed by different letters in every row are significantly different at the 95% confidence level

Table 5. Species composition of coleopterous predators in different years of assessment

Predator species	Years		
	2019	2020	2021
Upper stem part (thin bark)			
<i>Corticeus pini</i>	0	29.2 ± 9.28a	0
<i>Rhizophagus depressus</i>	0	0	25.0 ± 9.68a
<i>Platysoma elongatum</i>	0	41.6 ± 10.06a	25.0 ± 9.68a
<i>Aulonium ruficorne</i>	0	0	35.0 ± 10.67a
<i>Thanasimus formicarius</i>	0	29.2 ± 9.28a	15.0 ± 7.98a
Middle stem part (transitional bark)			
<i>Corticeus pini</i>	0	20.0 ± 5.16a	9.1 ± 6.13a
<i>Rhizophagus depressus</i>	0	20.0 ± 5.16a	13.6 ± 7.32a
<i>Platysoma elongatum</i>	0	8.3 ± 3.57a	27.3 ± 9.50b
<i>Aulonium ruficorne</i>	0	20.0 ± 5.16a	22.7 ± 8.93a
<i>Thanasimus formicarius</i>	0	23.3 ± 5.46a	18.2 ± 8.22a
<i>Thanasimus femoralis</i>	0	8.3 ± 3.57a	9.1 ± 6.13a
Lower stem part (thick bark)			
<i>Corticeus pini</i>	3.6 ± 2.52a	20.2 ± 2.63b	20.7 ± 4.48b
<i>Rhizophagus depressus</i>	1.8 ± 1.80a	19.3 ± 2.59b	17.1 ± 4.16b
<i>Platysoma elongatum</i>	41.8 ± 6.65c	6.4 ± 1.61d	12.2 ± 3.61e
<i>Aulonium ruficorne</i>	18.2 ± 5.20b	36.5 ± 3.15f	40.2 ± 5.42f
<i>Salpingus ruficollis</i>	0	0.9 ± 0.60g	0
<i>Thanasimus formicarius</i>	25.5 ± 5.87h	10.7 ± 2.03i	8.5 ± 3.09i
<i>Thanasimus femoralis</i>	9.1 ± 3.88j	6.0 ± 1.56j	1.2 ± 1.21k

Note: Means followed by different letters in every row are significantly different at the 95% confidence level

dant. On the samples of transition bark of the trees of the sixth class of the health condition, four predator species presented in a very close proportion. The propor-

tion of *C. pini* was much lower than in the trees of the fifth class of health condition, but it stayed abundant. In addition, *T. femoralis* was found in samples from the

transitional bark of trees of the sixth class, but it was common in terms of participation (Tab. 4). In the lower part of the trees of the fifth and sixth classes of health condition, six predator species were found. In the lower part of the trees of the fifth class of health condition, their proportion was from 4.4% (*T. femoralis*) to 28% (*A. ruficorne*). The last species was 58.1% in the lower part of the trees of the sixth class of health condition, while the proportions of *C. pini* and *T. formicarius* were only 4.7% each.

An analysis of the dynamics of the proportion of individual predator species showed that in 2019, they were found only in the trees of the lower part of the stem, with *P. elongatum* (41.8%) dominating. The second place was occupied by *T. formicarius* and the third place by *A. ruficorne* (Tab. 5).

In the samples with thin bark in 2020 and 2021, three and four species of predators were found, respectively. At the same time, *P. elongatum* dominated in 2020 and *A. ruficorne* dominated in 2021. The proportion of *T. formicarius* in the samples with thin bark in 2021 was almost half compared to 2020, but in 2021, *R. depressus* and *A. ruficorne* were found in such samples, where they were absent in 2020.

In the samples with transitional bark in 2020 and 2021, six species of predators were found and their ratio did not differ much in these years. One can only note a decrease in the proportion of *C. pini* from 20% to 9.1% and in the proportion of *T. formicarius* from 23.3% to 18.2% (Tab. 5).

In the samples with thick bark, the proportions of *C. pini*, *R. depressus* and *A. ruficorne* increased significantly in 2019–2021. At the same time, the participation of *P. elongatum*, *T. formicarius* and *T. femoralis* decreased. *S. ruficollis* was only identified in 2020 and made up only 0.9% of the collected predator species in this part of the stem.

In 2019, predators were found only under thick bark. In 2020, the predator–prey ratio increased from thin to thick bark and was the highest in 3 years (Tab. 6). In 2021, the predator–prey ratio was the lowest on thin bark and did not differ significantly from the transitional and thick bark. For 3 years, in all stem parts, the maximum predator–prey ratio was in 2020, and by stem sections, it was on the thick bark.

On the trees of the fourth class of health condition, the predators were found only under thick bark (Tab. 7).

Table 6. Coleopterous predator–prey ratio in different years and parts of stem

Sampled part of stem	Predator–prey ratio by years, %		
	2019	2020	2021
Upper (thin bark)	0.0a	2.75 ± 0.55b	5.78 ± 1.25c
Middle (transitional bark)	0.0a	7.46 ± 0.93d	7.94 ± 1.62cd
Lower (thick bark)	7.27 ± 0.94e	12.56 ± 0.77g	7.95 ± 0.84d
All samples	7.27 ± 0.71e	8.97 ± 0.48d	7.50 ± 0.65d

Note: Means followed by different letters are significantly different at the 95% confidence level

Table 7. Coleopterous predator–prey ratio in different parts of stem depending on health condition of the trees*

Sampled part of stem	Predator–prey ratio by the health condition tree classes		
	4 – drying up	5 – recently died	6 – died over a year ago
Upper, thin bark	0.0a	1.9 ± 0.54c	4.1 ± 0.70e
Transitional bark	0.0a	3.6 ± 0.76c	8.3 ± 1.08f
Lower, thick bark	16.1 ± 1.49b	9.3 ± 0.59d	7.0 ± 1.02f
All samples	12.4 ± 1.17b	7.1 ± 0.42g	6.3 ± 0.53f

Note: * Trees of the first and second classes of health condition were absent, and no gallery systems of bark beetles and their predators were found in the trees of the third class of health condition. Means followed by different letters are significantly different at the 95% confidence level.

On the trees of the fifth class of health condition, the predator–prey ratio increased from thin to thick bark, and on the trees of the sixth class of health condition, the highest predator–prey ratio was on the transitional bark. In the samples with thin and transitional bark, the predator–prey ratio was the highest in the trees of the sixth class of health condition. It may be explained by favourable microclimate or to be as a result of consuming other prey. In the lower stem part and in general, in the trees, the predator–prey ratio was the highest in the trees of the fourth class of health condition and decreased as the health condition of the trees deteriorated.

DISCUSSION

Cambiophagous insects are characterised by physiological and technical harmfulness. Physiological harmfulness depends on the ability of these insects to colonise the trees of a certain class of health condition, damage trees during maturation feeding and vector the pathogens into the trees (Skrylnik et al. 2019). In this regard, *I. acuminatus* is an aggressive species that inhabits not only trees of the third to fourth health condition classes, but also trees of the second class of health condition during an outbreak. *I. sexdentatus* is less aggressive and inhabits more weakened trees, including those that were previously inhabited by other bark beetles.

In our research, trees of the third to sixth classes of health condition prevailed in the collapsing foci and the health condition of the trees continued to deteriorate in 2019–2021 (Tab. 2). This was facilitated by vectoring the ophiostomatoid fungi by bark beetles (Davydenko et al. 2021).

Bark beetles are attracted to trees by volatiles, and predators are attracted to bark beetle pheromones (Schroeder 1999; Kenis et al. 2004). In the collapsing focus, bark beetles concentrate on drying up and dead trees and their predators also concentrate there.

The population density of bark beetles *I. acuminatus* and *I. sexdentatus* tended to decrease during the 3 years of the study. However, since *I. sexdentatus* is larger, its population density is considered 'normal' at lower values of this parameter. Data obtained show that the population density of *I. acuminatus* was 'normal' and that of *I. sexdentatus* exceeded the 'norm' (the 'normal' population density is 0.6–1 and 0.3–0.5 nuptial chambers per dm², respectively; Meshkova 2011).

In the galleries of bark beetles, seven species of predatory beetles were found. These species have a fairly wide range and are also known from other regions.

T. formicarius is a predator of many coleopterous species (Zondag 1979; Nikitsky 1980). It is reared in laboratories and released into the foci of *Ips typographus* (Linnaeus, 1758), *Dendroctonus* sp. and other bark beetles in different regions (Kenis et al. 2004; Warzee et al. 2006; Özcan and Koçoğlu 2021). *Th. femoralis* prefers denser stands (Nikitsky 1980). Adult *Pl. elongatum* prey on adults and larvae prey on the larvae of bark beetles (Cebeci and Baydemir 2018).

A. ruficorne is a Mediterranean species (Nikitsky 1980). It preys on *Orthotomicus* sp., *Pityogenes* sp., *I. sexdentatus*, *I. acuminatus*, *Dendroctonus micans* (Kugelann, 1794) and *Tomicus* sp. (Mendel et al. 1989; Podoler et al. 1990). *R. depressus* preys on *Pityogenes* sp., *I. sexdentatus*, *I. acuminatus*, *I. typographus*, *Orthotomicus* sp., *Tomicus* sp., *D. micans* and *Pityophthorus* sp. (Kharitonova 1972; Nikitsky 1980; Schroeder 1999).

C. pini preys on *I. sexdentatus* and *Orthotomicus* sp. (Nikitsky 1980; Zhukovsky et al. 2020). *G. quadripunctatus* is a facultative mycetophag (fungivorous species) and facultative predator. *P. depressus* preys not only on the larvae of Curculionidae and Cerambycidae, but also their natural enemies, particularly the larvae of *Medetera* and *Xylophagus*. It reduces the expediency of using this species for biological control (Kharitonova 1972; Nikitsky 1980).

The analysis showed the features in the distribution of predators on different parts of the stem and on the trees of different classes of health condition.

T. formicarius, *P. elongatum* and *A. ruficorne* were found in all parts of the stem. The trees of the fourth class of health condition were inhabited by predators only in the lower stem part. In the trees of the fifth class of health condition, the richest complex of predators was also found in the lower part of the stem (Tab. 3–5). This can be explained by the fact that in the lower stem part, the bark is the thickest with cracks in which predators can find shelter. They can feed on any part of the stem if there is a suitable prey, but they oviposit, rest and hibernate in the most favourable conditions that can be in the stem part with thick bark. However, in trees of the sixth class, the number of predator species in the middle and lower parts of the stem was the same (Tab. 4). *S. ruficollis* was found in low density only on the trees of the fourth class of health condition. This species is not known as a predator of bark beetles; it preys on Erotylidae and Leiodidae larvae (Krivosheyev 2009).

The ratio of predator–prey also varied by years and stem parts. This parameter averaged 7.27–8.97% for all stem parts (Tab. 6). In 2020, it significantly increased from the upper to the lower part of the stem, which could be due to the greater attractiveness of the thick bark to predators and the presence of a higher density of *I. sexdentatus*. In 2021, the predator–prey ratio in the stem parts with transitional and thick bark did not dif-

fer significantly. A comparison shows a significant decrease in the predator–prey ratio as the health condition of the tree worsens, which manifested itself in the lower stem part (Tab. 7). In the upper and middle stem parts, the predator–prey ratio in the trees of the sixth class of the health condition was significantly higher than in the fifth class trees. At the same time, in the group of trees of each health condition class, the minimum predator–prey ratio was noted in areas with thin bark. Such changes could be associated with more favourable conditions for predators in the lower stem part.

In studies conducted using flight barrier traps in central Sweden, the ratio of *T. formicarius*/*Tomicus piniperda* (Linnaeus, 1758) was 0.3–15.4% and 8–50.5%, and *R. depressus*/*T. piniperda* was 79.7–97.5% (Schroeder 1999). This author explains such variety with a different population density of the bark beetle in the compared stands, as well as with different phenological periods of assessment. Thus, the first ratio was calculated according to the data of swarming of 80% of *T. piniperda* individuals (in the second half of April) and the second and third ratios were calculated for the period that began 2 weeks after the beginning of the swarming of *Tom. piniperda* (April 24–June 6). In another study, the dependence of the predator–prey ratio on stand composition was proved (Warzee 2006). Thus, the variation of the predator–prey ratio is very high, and using it to predict trends in the development of the outbreak according to the available data does not seem appropriate.

CONCLUSIONS

1. In the collapsing foci of bark beetles (Coleoptera: Curculionidae: Scolytinae), the health condition of Scots pine in 2019–2021 tended to worsen. The infestation density of *I. acuminatus* and *I. sexdentatus* was 0.62 ± 0.032 and 0.64 ± 0.017 nuptial chambers per 1 dm², respectively, and also decreased in 2019–2021.
2. In the galleries of bark beetles, seven species of coleopterous predators were collected: *A. ruficorne*, *P. elongatum*, *R. depressus*, *C. pini*, *T. formicarius*, *T. femoralis*, *S. ruficollis*. Two more species – *G. quadripunctatus* and *P. depressus* – were singly collected in the foci. *T. formicarius* (44.4%) and *P. elongatum* (40.7%) were the most abundant.
3. The ratio of predator–prey significantly increased from the upper to the lower part of the stem with thick bark; however, it decreased in this stem part from the fourth to the sixth class of the health condition of the host tree.

REFERENCES

- Akkuzu, E., Şahin, M., Ugiş, A., Bal, E. 2021. Assessment of trap color and trap height above the ground on the capture of *Ips sexdentatus* and *Thanasimus formicarius*. *Şumarski list*, 145 (3/4), 169–174. DOI: <https://doi.org/10.31298/sl.145.3-4.6>
- Andreieva, O.Y., Goychuk, A.F. 2018. Spread of Scots pine stands decline in Korostyshiv Forest Enterprise. *Forestry and Forest Melioration*, 132, 148–154. DOI: <https://doi.org/10.33220/1026-3365.132.2018.148>
- Andreieva, O.Yu., Vyshnevskiy, A.V., Boliujh, S.V. 2019. Population dynamics of bark beetles in the pine forests of Zhytomyr region (in Ukrainian). *Scientific Bulletin of UNFU*, 29 (8), 31–35. DOI: <https://orcid.org/0000-0003-0851-800X>
- Anonimous. 2016. Sanitary Forests Regulations in Ukraine. Resolution of the Cabinet of Ministers of Ukraine No 756 dated 26 October 2016 (in Ukrainian). Available at: <https://zakon.rada.gov.ua/laws/show/555-95-п> (accessed on 15.02.2021).
- Beliavtsev, M.P., Skrylnik, Yu.Ye. 2020. The trophic structure of the subcortical entomofauna of Coleoptera in the deciduous plantations of the “Gomilshanski lisy” National nature park (in Ukrainian). *Biodiversity, Ecology and Experimental Biology*, 22 (1), 55–67. DOI: <https://doi.org/10.34142/2708-5848.2020.22.1.06>
- Cebeci, H.H., Baydemir, M. 2018. Predators of bark beetles (Coleoptera) in the Balikesir region of Turkey. *Revista Colombiana de Entomologia*, 44 (2), 283–287. DOI: <https://doi.org/10.25100/socolen.v44i2.7326>
- Colombari, F., Schroeder, M.L., Battisti, A., Faccoli, M. 2013. Spatio-temporal dynamics of an *Ips acuminatus* outbreak and implications for management. *Ag-*

- ricultural and Forest Entomology, 15, 34–42. DOI: <https://doi.org/10.1111/j.1461-9563.2012.00589.x>
- Davydenko, K., Vasaitis, R., Elfstrand, M., Baturkin, D., Meshkova, V., Menkis, A. 2021. Fungal communities vectored by *Ips sexdentatus* in declining *Pinus sylvestris* in Ukraine: focus on occurrence and pathogenicity of Ophiostomatoid species. *Insects*, 12 (12), 1119. DOI: <https://doi.org/10.3390/insects12121119>
- Fora, C.G., Lauer, K.F., Berar, C., Ștefan, C., Silivășan, M., Lalescu, D. 2012. Predators of *Pityogenes chalcographus* (Coleoptera: Scolytidae) in Natural Park Apuseni. *Journal of Horticulture, Forestry and Biotechnology*, 16 (1), 171–173.
- Hammer, O., Harper, D.A.T., Ryan, P.D. 2001. PAST: paleontological statistics software package for education and data analysis. *Palaeontologia Electronica*, 4, 1–9.
- Herard, F., Mercadier, G. 1996. Natural enemies of *Tomicus piniperda* and *Ips acuminatus* (Col., Scolytidae) on *Pinus sylvestris* near Orleans, France: temporal occurrence and relative abundance, and notes on eight predatory species. *Entomophaga*, 1996. 41, 183–210.
- Kharitonova, N.Z. 1972. Entomophages of coniferous bark beetles. *Lesnaya Promyshlennost*, 1–128 .
- Kenis, M., Wermelinger, B., Gregoire, J.C. 2004. Research on parasitoids and predators of Scolytidae – a review. In: European bark and wood boring insects in living trees. A synthesis (eds. F. Lieutier, K. Day, A. Battisti, J.C. Gregoire, H.F. Evans). Kluwer, Dordrecht, 237–290.
- Kereselidze, M., Wegensteiner, R., Goginashvili, N., Tvaradze, M., Pilarska, D. 2010. Further studies on the occurrence of natural enemies of *Ips typographus* (Coleoptera: Curculionidae: Scolytinae) in Georgia. *Acta Zoologica Bulgarica*, 62 (2), 131–139.
- Krivosheev, R.E. 2009. New Records of Xylomycetobiotic Beetles (Insecta, Coleoptera) from Kyiv Region (Ukraine). *Vestnik Zoologii*, 43 (6), e-13–e-17. DOI: 10.2478/v10058-009-0022-x
- Leontyev, D.V. 2008. Floristic analysis in mycology (in Russian). Ranok-NT, Kharkiv.
- Mendel, Z., Podoler, H., Livne, H. 1989. Establishment sequence and seasonal development of *Aulonium ruficornis* Olivier (Coleoptera: Colydiidae), a predator of bark beetles in pine plantations in Israel. *Acta Oecologica (Oecologia Applicata)*, 10 (2), 103–114.
- Meshkova, V. (ed.). 2011. Methodical recommendations for the inspection of foci of stem forest pests (in Ukrainian). UkrNDILGA, Kharkiv.
- Meshkova, V. 2021. The lessons of Scots pine forest decline in Ukraine. *Environmental Sciences Proceedings*, 3 (1), 28. DOI: <https://doi.org/10.3390/IECF2020-07990/>
- Meshkova, V.L. 2019. Decline of pine forest in Ukraine with the participation of bark beetles: causes and trends (in Russian). *Proceedings of the St. Petersburg Forest Technical Academy*, 228, 312–335. DOI: <https://doi.org/10.21266/2079-4304.2019.228.312-335>
- Meshkova, V., Bobrov, I. 2020. Parameters of *Pinus sylvestris* health condition and *Ips acuminatus* population in pure and mixed stands of Sumy region. *Proceedings of the Forestry Academy of Sciences of Ukraine*, 20, 131–140. DOI: <https://doi.org/10.15421/412012>
- Meshkova, V.L., Ridkokasha, A.D., Omelich, A.R., Baturkin, D.O. 2021. The first results of the biological control of *Ips sexdentatus* using *Thanasimus formicarius* in Ukraine. *Forestry and Forest Melioration*, 138, 91–96. DOI: <https://doi.org/10.33220/1026-3365.138.2021.91>
- Nikitsky, N.B. 1980. Insects-predators and their ecology (in Russian). Nauka, Moscow.
- Ostapenko, B.F., Vorobyov, D.V. 2014. Fundamentals of forest typology (in Russian). KhNAU, UkrNDILGA, Kharkiv.
- Özcan, G.E., Eroğlu, M., Alkan Akinci, H. 2021. Assessing the laboratory mass rearing of predator beetle *Rhizophagus grandis* Gyll. (Coleoptera: Monotomidae). *International Journal of Tropical Insect Science*, 41 (2), 1835–1843. DOI: <https://doi.org/10.1007/s42690-020-00417-z>
- Özcan, G.E., Koçoğlu, N. 2021. Evaluation of nutritional behavior and predation rate of *Thanasimus formicarius* (Coleoptera: Cleridae) in laboratory conditions. *International Journal of Tropical Insect Science*, 41 (2), 1673–1681. DOI: <https://doi.org/10.1007/s42690-020-00368-5>
- Podoler, H., Mendel, Z., Livne, H. 1990. Studies on the biology of a bark beetle predator, *Aulonium ruficornis* (Coleoptera: Colydiidae). *Environmental*

- Entomology*, 19 (4), 1010–1016. DOI: <https://doi.org/10.1093/ee/19.4.1010>
- Sanginés de Cárcer, P. et al. 2021. The management response to wind disturbances in European forests. *Current Forestry Reports*, 7 (4), 167–180. DOI: <https://doi.org/10.1007/s40725-021-00144-9>
- Sarikaya, O., Avci, M. 2009. Predators of Scolytinae (Coleoptera: Curculionidae) species of the coniferous forests in the Western Mediterranean Region, Turkey. *Turkiye Entomoloji Dergisi*, 33 (4), 253–264.
- Schroeder, L.M. 1999. Population levels and flight phenology of bark beetle predators in stands with and without previous infestations of the bark beetle *Tomicus piniperda*. *Forest Ecology and Management*, 123, 31–40. DOI: [https://doi.org/10.1016/S0378-1127\(99\)00014-6](https://doi.org/10.1016/S0378-1127(99)00014-6)
- Selikhovkin, A.V. 2017. Efficiency of sanitary measures in coniferous forests in current conditions on the example of the Leningrad region (in Russian). *Proceedings of the St. Petersburg Forest Technical Academy*, 221, 35–51. DOI: [10.21266/2079-4304.2017.221.35-51](https://doi.org/10.21266/2079-4304.2017.221.35-51)
- Skrylnik, Yu., Koshelyaeva, Y., Meshkova, V. 2019. Harmfulness of xylophagous insects for silver birch (*Betula pendula* Roth.) in the left-bank forest-steppe of Ukraine. *Folia Forestalia Polonica, Series A – Forestry*, 61 (3), 161–175. DOI: [10.2478/ffp-2019-0016](https://doi.org/10.2478/ffp-2019-0016)
- Warzee, N., Gilbert, M., Gregoire, J.C. 2006. Predator/prey ratios: a measure of bark-beetle population status influenced by stand composition in different French stands after the 1999 storms. *Annals of Forest Science*, 63, 301–308. DOI: [10.1051/forest:2006009](https://doi.org/10.1051/forest:2006009)
- Wermelinger, B., Rigling, A., Schneider Mathis, D., Kenis, M., Gossner, M.M. 2021. Climate change effects on trophic interactions of bark beetles in inner alpine Scots pine forests. *Forests*, 12 (2), 136. DOI: <https://doi.org/10.3390/f12020136>
- Yaman, M., Algi, G., Ünal, S., Güner, B.G. 2016. Survey of pathogens and parasites of the engraver beetle *Ips acuminatus* (Gyllenhal, 1827) (Coleoptera: Curculionidae: Scolytinae) in Turkey. *Acta Zoologica Bulgarica*, 68 (1), 127–130.
- Zhukovsky, O.V., Orlov, A.A., Cherney, L.S., Nazarenko, V.Yu. 2020. Data to biology and ecology of darkling beetles *Corticus longulus* and *C. pini* (Coleoptera: Tenebrionidae) in Ukrainian Polessye. Modern problems of forest protection and ways of their solution. In: Materials of the II International research-to-practice conference in commemoration of 95th anniversary of Professor Nikolai Ilyich Fedorov, and the 90th anniversary of the Department of Forest Protection and Wood Science (eds. V.B. Zviagintsev, M.O. Siaredzich), November 30–December 4, 2020, Minsk, 105–109.
- Zondag, R. 1979. Breeding of the clerid *Thanasimus formicarius* for the control of the bark beetles *Hylastes ater* and *Hylurgus ligniperda* in New Zealand. *New Zealand Journal of Forestry Science*, 9, 125–132.