

Interannual population dynamics of *Scaphoideus titanus* adults in Kosovo vineyards based on a three-year field surveillance program

Gazmend Gjinovci^{1,2}, Adnand Ramadhi¹, Shpend Shahini¹,
Betim Bresilla^{2,3}, Rayane Saifi⁴, Bekri Xhemali^{2,5*}

¹ Department of Plant Protection, Agricultural University of Tirana, Tirana, Albania

² Laboratory of Plant Protection, Kosovo Institute of Agriculture, Pejë, Kosovo

³ Institute of Environmental Sciences, Department of Soil Science, Hungarian University of Agriculture and Life Sciences, Páter Károly u. 1, Gödöllő, Hungary

⁴ Research Laboratory of Sciences and Environment: Bioresources, Geochemical-Physics, legislation and socio-economic development, University of Tamanrasset, Tamanrasset, Algeria

⁵ Faculty of Agribusiness, University Haxhi Zeka, Pejë, Kosovo

* Corresponding author's e-mail: xhemalibekri@gmail.com

ABSTRACT

Scaphoideus titanus is a monophagous grapevine leafhopper and the primary vector of *Flavescence dorée* phytoplasma (FDp), a major quarantine pathogen threatening European viticulture. Following its recent detection in Kosovo, detailed information on the population dynamics and spatial distribution of this invasive vector under local conditions is essential for phytosanitary risk assessment and management. This study investigated the seasonal abundance, spatial variability, and temporal trends of *S. titanus* populations in the Rahovec viticulture region through a three-year monitoring program conducted from 2023 to 2025. Adult populations were monitored using yellow sticky traps installed at canopy level across 25 georeferenced sampling locations distributed among four representative vineyard localities. Traps were inspected and replaced weekly from late May to early October, covering the full period of adult activity. The findings showed a continuous increase in the number of adults over the period of the investigation accompanied by high spatial variation at the sampled locations. The highest number of adults was found consistently in Rahovec, specifically at sampling points 11 and 16 with annual maximum adult increasing from 482 to 592 for point 11 and from 81 to 580 for point 16. Adult emergence shifted toward earlier seasonal occurrence with first detections moving from July in 2023 to earlier in June in 2025. The sites with high abundance corresponded to lowland vineyards and those dominated by Vranç varieties. This study provides the first comprehensive spatiotemporal assessment of *S. titanus* populations in Kosovo and identifies key ecological factors associated with increased vector abundance. The findings support the implementation of targeted monitoring and specific management strategies.

Keywords: *Scaphoideus titanus*, adult population monitoring, vineyard ecosystems, invasive vector, Kosovo.

INTRODUCTION

Scaphoideus titanus Ball (Hemiptera: Cicadellida) is an ampelophagous, xylem feeding leafhopper, originating from the North America. Its earliest records in Europe emerged in the late 1950's and it has settled into many viticultural

areas throughout Europe, mainly due to its association with cultivated *Vitis vinifera*. After being accidentally introduced into southwestern France in the late 1950s, *Scaphoideus titanus* Ball has steadily expanded its geographic distribution in the viticulture areas of Europe. Long-term populations were subsequently established

in Italy, and across the Balkan Peninsula. Scientific reports emerged from later detections in Spain and Portugal, demonstrating that invasion and adaptation of *Scaphoideus titanus* was successfully to new agricultural ecologies associated with *Vitis vinifera* production (Ripamonti et al., 2022; EFSA, 2020). The Nearctic leafhopper *Scaphoideus titanus* Ball has been slowly expanding its range in southeastern Europe. The first confirmed finding of *Scaphoideus titanus* in the Balkans was recorded in Serbia in 2004 (Magud and Toševski, 2004), then in Montenegro in August 2008 (Radonjić et al., 2008). The recent record of this species has been captured in Kosovo (Gjinovci et al., 2022) which highlights that this invasive pest is continuing to increase its spatial distribution across the Balkan Peninsula with serious implications for viticulture and phytosanitary status in the region.

Scaphoideus titanus is a singular taxonomic unit with a high degree of host specificity, requiring *Vitis* spp. for oviposition and morphological development in the life cycle. This species overwinters as dormant eggs only, under the bark of grape crushed canes. The cold conditions of winter will influence the timing and synchrony of early May egg hatch, based on climatic conditions in the infested area. The first adult stage occurs from late June to July (EFSA, 2025; Gonella et al., 2024). *Scaphoideus titanus* females oviposit from August to October by laying their eggs under the shedding bark of mature grapevine canes, where they overwinter in a dormant state. Importantly, the host plants must be at least two years old, since younger vines do not produce sufficient bark and a well-developed internal structure for egg insertion and safety.

Scaphoideus titanus Ball is currently known as the main vector of *Flavescence dorée* phytoplasma (FDp, subgroup 16SrV-C/D) which is capable of transmitting FDp from infected to healthy grapevines, and is therefore the major pathogen vector of this economically important quarantine disease in viticulture. Nymphs and adults can both serve as competent vectors of *Flavescence dorée* phytoplasma (FDp), able to acquire and transmit the pathogen during feeding on *Vitis vinifera* (Arricau-Bouvery et al., 2021; Bocca et al., 2020). The adult stage of *Scaphoideus titanus* is the most significant stage in the epidemiology of *Flavescence dorée* because it has a relatively short pathogen latency

period but a relatively long lifespan, thus allowing a long period of FDp transmission (Bocca et al., 2020; Alma et al., 2018). Since *Scaphoideus titanus* adults can fly up to 300 m in distance and can acquire FDp inoculum from nearby vineyards and wild host plants, timely and extensive monitoring of the adult population is important to developing effective and sustainable management strategies for *Flavescence dorée* (Ortis et al., 2025). The aim of this study was to investigate changes to the population dynamics of *Scaphoideus titanus* over a three-year period from 2023–2025 in Rahovec, specifically in this area because it is one of the main viticulture regions within Kosovo. The goal of this study was to provide adequate temporal data on seasonal abundances and activity of the vector, to assist in understanding better the phenological characteristics of the pest in relation to the local agro-ecological environment.

MATERIAL AND METHODS

Study area

This research was carried out in the Rahovec region which is a major region for grape growing in Kosovo, situated in the southwestern part of Kosovo (Figure 1). The decision to conduct this research arose upon the first confirmed sighting of having detected the insect *Scaphoideus titanus*, the primary insect vector that transmits the phytoplasma *Flavescence dorée* (Gjinovci et al., 2022). The climate of this area is known to be of a continental type, with Mediterranean-type influences and warm summers to relatively cold winters; however, there is also much diversity in geomorphology, including valley systems and mid-elevational vineyard settings. Most vineyards are planted to the Vranac variety which is known for its autochthonous representation in the region.

The objectives of this particular research study are to characterize the seasonal biology, annual population dynamics and spatial distributions of *S. titanus* in the local agroecological environment by conducting a three-year structured surveillance program (2023 to 2025) that will generate baseline epidemiological data to support phytosanitary risk assessments and integrated pest management programs for *S. titanus* in this region.

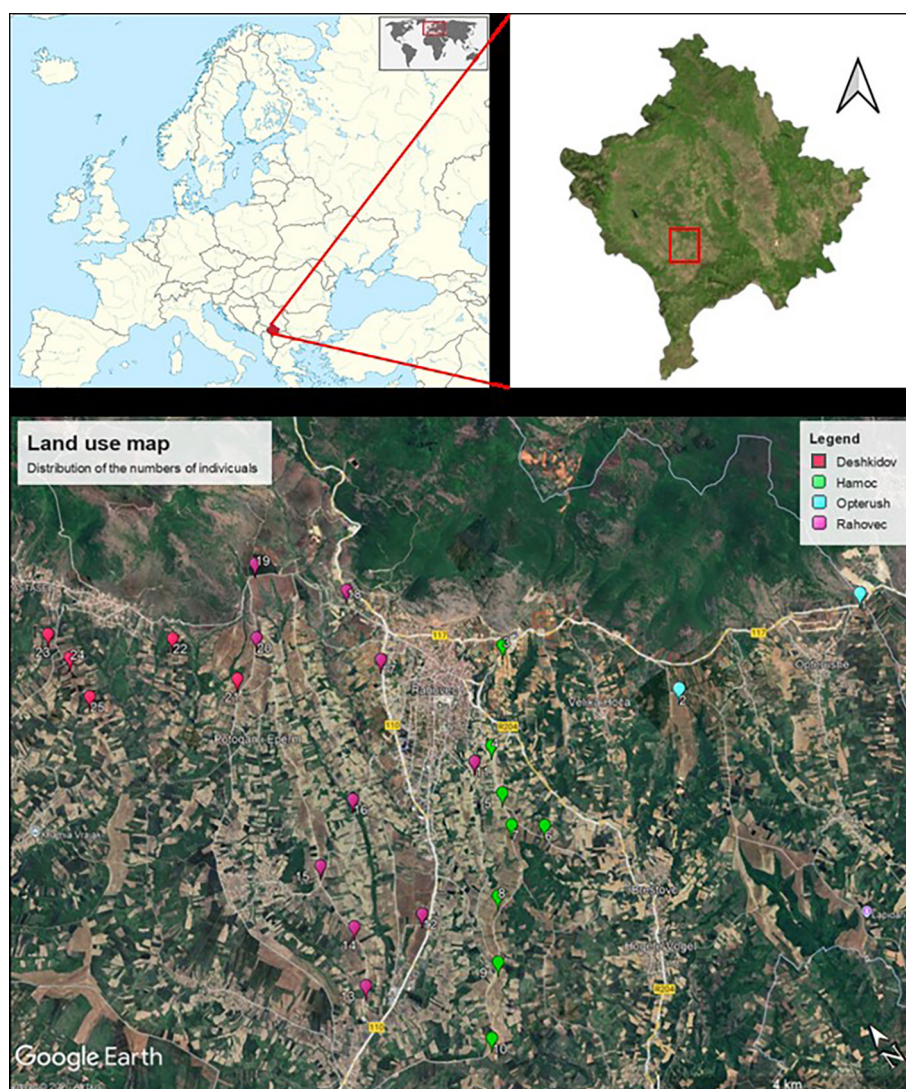


Figure 1. Spatial distribution of the 25 georeferenced sampling sites across four distinct localities within the Rahovec region, designated for monitoring *Scaphoideus titanus*

EXPERIMENTAL DESIGN

Study site selection

Four representative locations from the Rahovec region were selected to sample at 25 georeferenced sampling sites which were installed at fixed monitoring sites within the same vineyards. The four selected locations are Rahovec, Hamoc, Deshkidov, and Opterush. The 25 surveyed vineyards were managed under good agricultural practices with routine vineyard operations conducted throughout the growing season which includes pruning, canopy management, weed control, soil management, irrigation where required, and other standard cultural practices. Insecticide treatments were applied by growers when considered necessary according to their routine pest management

practices. No experimental insecticide treatments were imposed during the study. The 25 sampling points were monitored under the prevailing commercial management practices of the respective vineyards. During the field visits, local farmers reported that approximately two insecticide applications were commonly conducted during three growing seasons with insecticides containing acetamiprid, imidacloprid, deltamethrin, and cypermethrin among the active ingredients used. As these applications were part of routine farmer management and were not experimentally controlled, insecticide use was not included as an experimental factor in the statistical analysis. The vineyards at the sampling points were approximately 20 years old on average, representing predominantly mature and established vineyard systems. Sampling sites were selected to capture variation in

altitude, topographic relief, and grapevine cultivar within the surveyed area. The sampling locations have been selected that they comprised vineyards which were located at different altitudes and relief categories which included relatively flat, hilly, and sloping terrain, as well as vineyards planted with the main cultivated grapevine varieties. Other agronomic practices were maintained according to the routine management of farmers and were therefore not standardized experimentally among sampling points. This selection strategy of the study sites made it possible to study the spatial variability in the number of adults of *Scaphoideus titanus* in relation to altitudinal and topographical and cultivar variability.

Climatic data collection

To assess the influence of temperature variability on the developmental dynamics of *Scaphoideus titanus*, monthly temperature (Table 1) data were collected to each surveyed site. These data were obtained from the nearest meteorological stations of Prizren, managed by the Hydrometeorological Institute of Kosovo, and were recorded throughout the monitoring periods (April to October) in 2023, 2024, and 2025. Climatic data collected during the three years of monitoring (2023–2025) was statistically evaluated through ANOVA to determine variations in climatic parameters between the monitoring years. These data were used to analyze the relationship between temperature fluctuations and the occurrence of adult population.

Sampling method in vineyards

The population of adults of *S. titanus* was monitored using single yellow sticky traps (Insect Trap Aria®, 10 × 25 cm) that were placed in each surveyed vineyards in order to ensure adequate spatial distribution across four locations. The monitoring method has been recommended for the adult stage of leafhoppers (Ortis et al., 2025; EFSA, 2020). In order to ensure that the initial occurrence of adults was not missed, yellow sticky traps were installed at each sampling point in late May and maintained throughout the surveillance period until early October during each monitoring year (2023–2025). The first confirmed appearance of adult *S. titanus* was recorded on 27 June in the respective monitoring year based on the trap inspections. From the first confirmed adult detection, weekly monitoring of the adult population was continued. The date of the first recorded appearance of adult *S. titanus* was subsequently documented for each sampling point and year based on the weekly trap inspections and is reported in the Supplementary Table 1. The traps have been changed every seven days, starting from the onset of adult emergence until early autumn. Throughout the growing season all traps were examined and replaced on a weekly basis, in order to determine fluctuations in the abundance of adult *Scaphoideus titanus* over time. The data collected from this longitudinal study is crucial in understanding the spatiotemporal patterns of the population dynamics of *Scaphoideus titanus*. These findings will also be useful

Table 1. Yearly temprature for three years of adult monitoring

Months	Average temperature in three years of monitoring		
	2023	2024	2025
January	3.9	3.6	4.5
February	4.6	9	3.7
March	8.9	10.5	10.9
April	10	15.2	14.9
May	15.9	18.0	16.3
June	19.8	25.3	25.5
July	25	27.1	26.8
August	23.3	26.4	26.6
September	20.8	19.6	21.2
October	16	13.8	12.4
November	8.7	5.2	8.8
December	5.1	3.3	2.6
Average yearly temp.	13.5	14.8	14.7

in the formulation of management strategies for the prevention and control of *Flavescence dorée* in different regions.

Collection, storage and laboratory processing

The use and collection of yellow sticky traps was done on a weekly basis and each of these traps were labelled and marked with a unique site code and sampling date to ensure that each was identifiable and traceable throughout the entire process. The number of adult *Scaphoideus titanus* captured using the yellow sticky traps was determined manually on a weekly basis. This included inspecting each yellow sticky trap independently and counting the number of morphologically identified adults. Once the traps had been collected from the field, they were placed into protective covers to prevent cross-contamination and then they were transported for processing to the Laboratory of Plant Protection at the Kosovo Institute of Agriculture. The captured *Scaphoideus titanus* specimens were removed from the sticky surfaces of the traps using fine-tipped entomological forceps; care was taken under stereomicroscopy so not to cause any morphological damage to the specimens. Once the *Scaphoideus titanus* specimens had been removed, they were transferred into glass vials which contained 70% ethanol for long-term preservation. Each vial was properly labelled with key collection data, including site, trap number and sampling date. The preserved specimens were maintained at room temperature under controlled laboratory conditions until morphological identification and verification was completed. Representative specimens of *Scaphoideus titanus* from each year and locality were deposited in the institutional entomological reference collection to ensure reproducibility and to support future taxonomic and molecular studies.

Identification procedure and taxonomic key

The morphological and morphometric characterization of adult specimens was carried out using a stereomicroscope and supported by reliable diagnostic keys for the descriptions of the species (EFSA, 2020; Gonella et al., 2024). The identification of the species followed general guidelines for entomological identification which are specific to the family Cicadellidae to guarantee taxonomic reliability. For species

identification, a range of external morphological characteristics were considered, such as body size and general coloration patterns. In particular, cephalic morphology, including head and pronotum shape and coloration, was considered a key feature for species identification. In particular, efforts were made to distinguish *Scaphoideus titanus* from other sympatric leafhopper species commonly encountered in vineyard environments. In cases of ambiguous morphological traits or damaged specimens, re-examination of the specimens was carried out to guarantee taxonomic reliability and consistency.

DATA ANALYSIS

All statistical analysis and graphical visualization were performed using R statistical software (version 4.4.2, 2025). Summary descriptive statistics were calculated for 2023 to 2025 and for each unique location within the study area for the total number of *Scaphoideus titanus* individuals collected by all traps. To explore the variation in the number of individuals at different sampling locations and years, boxplot graphs were created using R statistical software with the ggplot2 package by employing the ggplot() function along with the geom_boxplot() function.

RESULTS AND DISCUSSIONS

Scaphoideus titanus adults were monitored using yellow sticky traps (Figure 2) placed at the designated sampling points within the vineyards. Traps were checked and changed at weekly intervals throughout the monitoring period. During the weekly check, the dispensable trap was examined in the laboratory, and all captured adult specimens identified morphologically as *S. titanus* were counted manually. Species identification was carried out using the key morphological and morphometric characteristics as body structure, color, wing condition, and size. The number of adult *S. titanus* was counted for each sampling site and weekly monitoring day. In total, there were 25 sampling sites (1–25) which were monitored with one trap placed at each sampling site. The content of traps was monitored weakly and the number of adult *S. titanus* collected within each trap was counted on a weekly monitoring day. The counts included only undamaged specimens.

If any specimen was damaged or not adequately undamaged to be identified was not considered indeterminate and was not counted. All counted data were then presented in a structured dataset that included trapping points, sampling date, and total number of trapped adults of *S. titanus* (Supplementary Table 1). Such data were used for the characterization of temporal and spatial dimensions of adult population dynamics.

The morphological identification of *Scaphoideus titanus* was conducted on the basis of some external diagnostic features reported in taxonomic and diagnostic literature. Adult specimens were characterized by a long body that was relatively thin with coloration varying from brownish-yellow to brown or dark brown particularly on the wings and back. The adults have developed wings that cover and extend above the abdomen and the head has a characteristic triangular shape (Figure 3). The body length of adult specimens was approximately 5.3 mm. Additionally, morphometric analysis of the collected specimens of *Scaphoideus titanus* showed that there is an evident sexual dimorphism between the sexes of the species on the basis of body length. The females of this

species proved to be much larger in size, with an average body length of 5.5 mm from the tip of the vertex to the extremities of the forewings. On the other hand, the males of this species proved to be significantly smaller, with an average body length of 4.7 mm (Figure 4a and 4b). Adults were head markings (sexual dimorphism): red-brown transverse bands line the transition from the vertex (top of the head) to the face. Females exhibited 3 dark transverse bands (Figure 5a), whereas males displayed only 1 (Figure 5b). The female has a sturdy golden brown ovipositor which is used to lay eggs in the branches (Figure 6). Examination of the male genitalia revealed long pygofer setae may be detached during specimen handling and preparation (Figure 7). These morphological and morphometric characteristics were consistent with the diagnostic descriptions of *S. titanus* provided by Chuche and Thiéry (2014), EPPO, (2016), and Gonella et al. (2024). The results of the three-year population surveillance highlighted spatial variation in the density of *Scaphoideus titanus* in the monitored vineyards of the Rahovec viticulture region. Overall, the results showed an increasing trend in the adult population over the

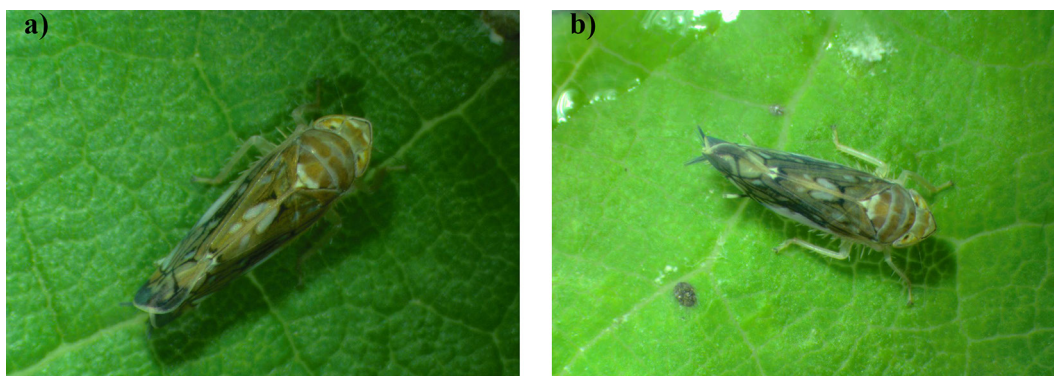


Figure 2. a) Yellow sticky traps, b) adult attached in yellow sticky traps

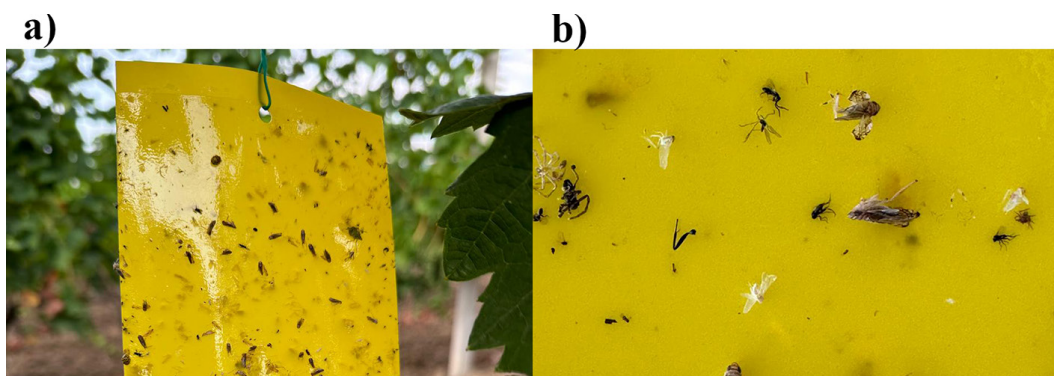


Figure 3. Morphological characteristics of adult *Scaphoideus titanus*

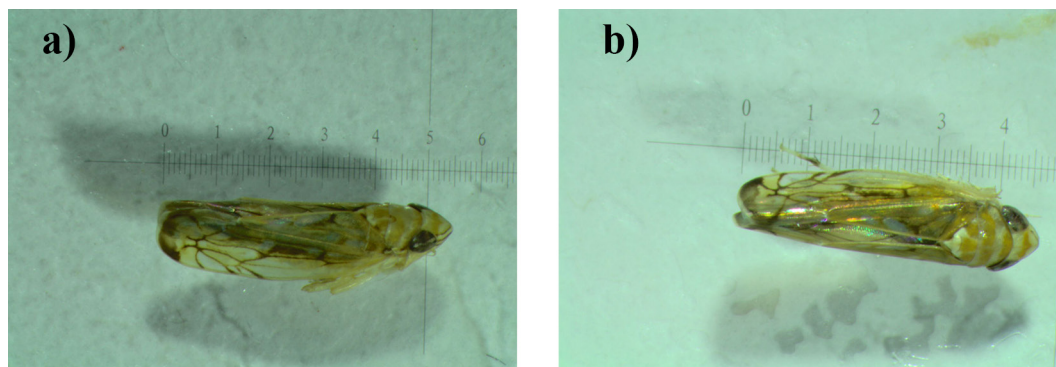


Figure 4. Morphometric measurements of collected *S. titanus* specimens: (A) female specimen with an average body length of 5.5 mm; (B) male specimen with an average body length of 4.7 m

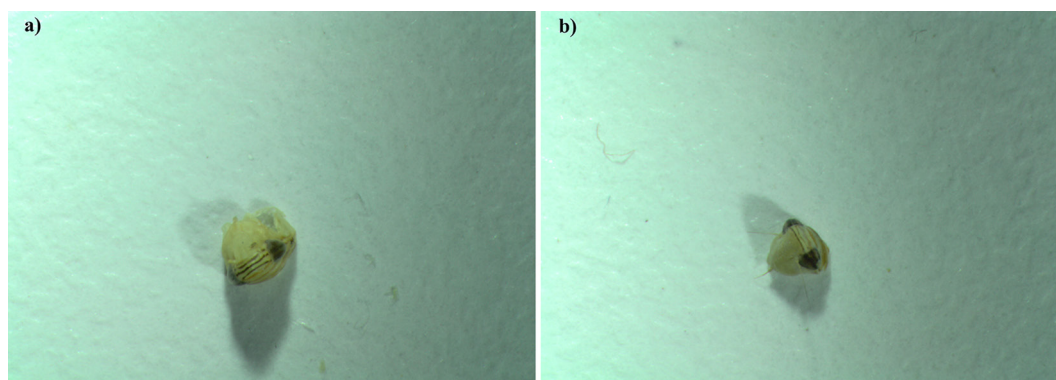


Figure 5. a) Head of female adult with three dark transverse bands, b) head of male adult with one dark transverse bands



Figure 6. The female golden brown ovipositor

years, and the Rahovec site recorded the highest cumulative number of individuals compared to Deshkidov, Hamovc, and Opterush. Based on Table 2 the population monitoring data highlighted considerable spatial and temporal heterogeneity of the adult insect population size at the 25 sampling points for the three surveying years. During 2023, the mean minimum and maximum

population sizes at the sampling points were about 27.8 and 82.6, respectively. Moreover, for 2024 the mean minimum and maximum values of the population size at the sampling points increased to 34.0 and 119.8, respectively. For 2025, the mean maximum population size increased to approximately 139.6, whereas the mean minimum population size stayed almost at the same level as it was in 2023 (28.2) (Figure 8). Therefore, we can conclude that the changes in population size throughout the monitoring period occurred mostly in terms of increases in population maxima and not uniformly at all sampling points. There was a clear variation between the sampled points in all three years. The population densities were relatively higher in the Rahovec sampling locations, especially in sampling points 11, 14, 16 and 20. For instance, in sampling point 11, the highest population density was 482, 554 and 592 for 2023, 2024 and 2025, respectively, making it the highest population ever seen at this point during the surveyed period. Similarly, in sampling area 16, the maximum population density was 81, 433

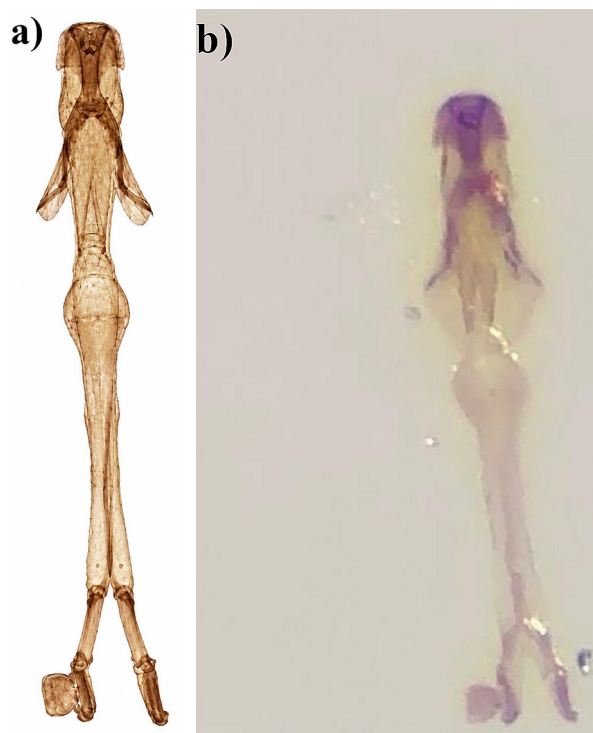


Figure 7. a) Adult male genitalia (edited figure to ensure clear visibility), b) adult male genitalia directly observed under stereomicroscope

and 580 in 2023, 2024 and 2025, respectively. In sampling area 14, the maximum population densities were 235, 267 and 296 in 2023, 2024 and 2025, respectively. Furthermore, variations were also apparent in Hamovc locations. Point 7 was one of the most interesting sites with maximum number increasing from 200 adults in 2023 to 300 in 2024 and to 386 in 2025. The rest of the locations in Hamovc had much smaller numbers of adults proving that the abundance was very localized. This trend was typical for the Deshkidov-Drenoc location as well. However, the differences were not so drastic. Adult population differed from each other for the five different points. The highest number reached point 24 which captured 109 adults in 2023, 135 in 2024 and 167 in 2025. Some of the points had much lower population density. The box-plot analysis (Figure 8) indicates considerable variability both in terms of spatial distribution and inter-annual variation of *Scaphoideus titanus* adults' population size in the four monitored vineyards localities over the period from 2023 to 2025. This pattern over time was statistically validated with the help of Friedman's test for repeated measurements at the same monitoring points ($\chi^2 = 34.16$, $df = 2$, $P < 0.001$) showing that there is an evident inter-annual difference in adult population size. This difference

was confirmed in terms of pairwise comparison using Wilcoxon signed-rank test: 2023 vs. 2024 ($P < 0.001$), 2024 vs. 2025 ($P = 0.003$), and 2023 vs. 2025 ($P < 0.001$). However, Kruskal–Wallis comparisons among the four localities did not detect statistically significant differences in any individual year (2023: $P = 0.627$; 2024: $P = 0.821$; 2025: $P = 0.802$). Therefore, the higher absolute counts observed in Rahovec are interpreted as a descriptive spatial pattern, rather than as evidence of statistically significant differences among the four geographical localities.

The observations of the first adult detection dates provided evidence that there was a gradual progression to earlier activities during the three-year monitoring period. The observations of the first adult occurrence of the insect in 2023 were mostly made in July while in 2024 the adult was first recorded in the first half of July in various monitoring points. Whereas, in 2025 the first adult occurrence has already been reported in 27 June 2025. This early appearance could adhere to the overall increase in temperature for the monitoring years, which means that the climate conditions may have favorably affected the seasonality of the insect activity. From the information provided in Table 1 about the temperature for 2023–2025, the average temperature rose from 13.5 °C in 2023 to

Table 2. Yearly monitoring of 25 georeference points, adult first appearance and adult total yearly population

Year of monitoring	Locality	Point number	First adult appearance	Adult minimum population	Adult maximum population	Adult total annual population
2023	Opterush	1	27.07.2023	2	11	35
	Opterush	2	17.08.2023	1	2	5
	Hamovc	3	27.07.2023	1	13	32
	Hamovc	4	20.07.2023	2	36	180
	Hamovc	5	13.07.2023	1	16	46
	Hamovc	6	20.07.2023	1	6	48
	Hamovc	7	06.07.2023	1	38	200
	Hamovc	8	13.07.2023	1	25	92
	Hamovc	9	27.07.2023	1	11	46
	Hamovc	10	03.08.2023	1	6	8
	Rahovec	11	13.07.2023	3	152	482
	Rahovec	12	03.08.2023	1	1	1
	Rahovec	13	13.07.2023	1	19	64
	Rahovec	14	20.07.2023	1	118	235
	Rahovec	15	17.08.2023	1	5	13
	Rahovec	16	20.07.2023	1	56	81
	Rahovec	17	13.07.2023	1	3	6
	Rahovec	18	20.07.2023	1	4	16
	Rahovec	19				0
	Rahovec	20	20.07.2023	2	97	263
	Deshkidov - Drenoc	21	03.08.2023	1	7	18
	Deshkidov - Drenoc	22	03.08.2023	1	1	1
	Deshkidov - Drenoc	23	03.08.2023	2	17	35
	Deshkidov - Drenoc	24	20.07.2023	1	32	109
	Deshkidov - Drenoc	25	20.07.2023	2	20	50
2024	Opterush	1	13.07.2024	1	14	64
	Opterush	2	27.07.2024	1	6	25
	Hamovc	3	20.07.2024	1	17	58
	Hamovc	4	20.07.2024	1	10	33
	Hamovc	5	13.07.2024	1	19	63
	Hamovc	6	13.07.2024	1	10	53
	Hamovc	7	01.07.2024	1	109	300
	Hamovc	8	06.07.2023	2	31	129
	Hamovc	9	13.07.2024	2	13	74
	Hamovc	10	20.07.2024	2	9	42
	Rahovec	11	01.07.2024	2	125	554
	Rahovec	12	27.07.2024	1	6	16
	Rahovec	13	13.07.2024	1	22	74
	Rahovec	14	13.07.2024	1	128	267
	Rahovec	15	27.07.2024	1	8	33
	Rahovec	16	06.07.2024	1	90	433
	Rahovec	17	06.07.2024	1	26	87
	Rahovec	18	13.07.2024	1	5	38
	Rahovec	19	10.08.2024	2	4	9
	Rahovec	20	13.07.2024	1	105	307
	Deshkidov - Drenoc	21	20.07.2024	2	9	47
	Deshkidov - Drenoc	22	20.07.2024	1	5	18
	Deshkidov - Drenoc	23	20.07.2024	1	21	62
	Deshkidov - Drenoc	24	13.07.2024	1	35	135
	Deshkidov - Drenoc	25	13.07.2024	2	23	75

Table 2. Cont. Yearly monitoring of 25 georeference points, adult first appearance and adult total yearly population

2025	Opterush	1	27.06.2025	1	10	90
	Opterush	2	03.08.2025	1	4	14
	Hamovc	3	27.06.2025	1	15	57
	Hamovc	4	13.07.2025	1	7	25
	Hamovc	5	06.07.2025	1	14	80
	Hamovc	6	27.06.2025	1	10	76
	Hamovc	7	27.06.2025	1	85	386
	Hamovc	8	01.07.2025	1	26	152
	Hamovc	9	06.07.2025	1	10	90
	Hamovc	10	06.07.2025	1	7	37
	Rahovec	11	27.06.2025	1	95	592
	Rahovec	12	13.07.2025	1	5	22
	Rahovec	13	01.07.2025	1	27	104
	Rahovec	14	06.07.2025	1	115	296
	Rahovec	15	06.07.2025	1	6	41
	Rahovec	16	01.07.2025	2	82	580
	Rahovec	17	01.07.2025	1	21	70
	Rahovec	18	27.06.2025	1	5	45
	Rahovec	19	20.07.2025	1	3	15
	Rahovec	20	01.07.2025	1	81	320
	Deshkidov - Drenoc	21	13.07.2025	2	7	65
	Deshkidov - Drenoc	22	06.07.2025	1	6	50
	Deshkidov - Drenoc	23	01.07.2025	1	18	54
	Deshkidov - Drenoc	24	27.06.2025	1	29	167
	Deshkidov - Drenoc	25	01.07.2025	1	18	61

significant ($F = 58.183$, $p < 0.001$) which confirms the expected strong seasonal pattern in temperature. Pearson correlation between year and monthly temperature was also non-significant ($r = 0.051$, $p = 0.766$). Therefore, spatial and temporal trends identified in the Rahovec viticulture region support previous findings that described the irregular distribution and gradual spread of *Scaphoideus titanus* in European vineyards. The trend of increasing adult population from 2023 to 2025, especially at Rahovec is consistent with data from other parts of southern and southeastern Europe, where vector populations are increasing under favorable climatic conditions and viticulture management (Rigamonti et al., 2018). In addition, the boxplot analysis in Figure 8 also highlights the substantial degree of variation in the adult population size at the four locations studied over the period of 2023 to 2025.

Based on Table 3, considerable spatial variation was revealed at the twenty-five sampling points regarding the elevation, geomorphological features and utilized grapevine varieties.

14.8 °C in 2024 and 14.7 °C in 2025, where the highest temperatures occurred in the months of June–August. Increase in temperature during the specified season is concurrent with an increase in the number of *Scaphoideus titanus* adults which shows a positive temporal relationship between temperature increase and adult development. Specifically, the increase in the number of adults was concurrent with an increase in temperatures of 25–27 °C in the late spring and summer seasons. It is, therefore, possible to say that high temperatures might have favored the development and growth of adults in the specified period. Furthermore, the available monthly temperature data (Table 1) for the three monitoring years (2023–2025) has been statistically analyzed using ANOVA. A one-way ANOVA showed that the differences in monthly mean temperature among the three years were not statistically significant ($F = 0.075$, $p = 0.928$). In addition, a two-way ANOVA considering year and month showed that the effect of year was not significant ($F = 1.500$, $p = 0.245$), whereas the effect of month was highly

Monitoring points had altitudes ranging from approximately 354 m to 548 m and belonged to four categories: lowland, flat-land, slope, and hill. The lowest sampling points belonged to the Rahovec locality, while the highest sampling points

were noted at two locations in Rahovec (548 meters) and Opterush (518 meters). The fact that the spatial variation of *S. titanus* abundance found in various monitoring sites is aligned well with previous research showing that the occurrence

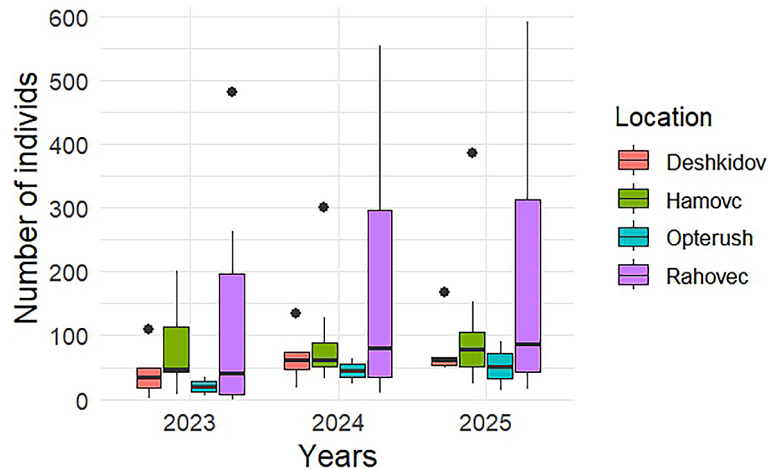


Figure 8. Box plot analysis of adult *Scaphoideus titanus* populations across the four study sites, highlighting spatial and temporal variability of adult populations during 2023–2025

Table 3. Detailed information about 25 georeference points about altitude, relief and cultivar

Locality	Point	Altitude	Relief	Cultivar
Opterush	1	512	Flat land	Afuzali
Opterush	2	482	Flat land	Merlot
Hamovc	3	480	Flat land	Cardinal
Hamovc	4	457	Hill	Rizling
Hamovc	5	460	Hill	Vranç
Hamovc	6	451	Slope	Cardinal
Hamovc	7	460	Hill	Vranç
Hamovc	8	443	Slope	Vranç
Hamovc	9	415	Slope	Smederevkë
Hamovc	10	421	Slope	Viktoria
Rahovec	11	408	Lowland	Vranç
Rahovec	12	358	Lowland	Vranç
Rahovec	13	354	Lowland	Zhamete
Rahovec	14	388	Slope	Merlot
Rahovec	15	440	Hill	Muscat hamburg
Rahovec	16	387	Lowland	Vranç
Rahovec	17	488	Slope	Black magjik
Rahovec	18	515	Hill	Cardinal
Rahovec	19	548	Hill	Prokupe
Rahovec	20	505	Slope	Vranç
Deshkidov - Drenoc	21	491	Slope	Zhamete
Deshkidov - Drenoc	22	491	Hill	Vranç
Deshkidov - Drenoc	23	487	Slope	Shardone
Deshkidov - Drenoc	24	485	Flat land	Rizling
Deshkidov - Drenoc	25	469	Slope	Vranç

and population density of agricultural pests can be very heterogeneous due to the effect of environmental and site-specific factors. This variability could be linked to differences in the environment and features specific to each vineyard. Initial exploratory data analysis indicated weak to moderate negative correlations between altitude and annual abundance of the insect without statistical significance (Spearman's $\rho = -0.33$, $P = 0.104$ for 2023; $\rho = -0.25$, $P = 0.220$ for 2024; $\rho = -0.27$, $P = 0.196$ for 2025). Likewise, there was no difference in abundance among different topographic classes (all $P > 0.05$). From these findings is concluded that altitude and topography are sources of local variability. However, there is no sufficient evidence at the moment to state that either of these two factors independently determines the population abundance of *S. titanus*. Spatial data analysis of previous study has applied the possibility of identifying spatial and temporal changes pest occurrence in various sampling points (Minh et al., 2024).

The increase in *S. titanus* over the period of 3 years of monitoring may demonstrate the ability of insects to invade agricultural lands and spread in these areas. Similar studies on pest spread dynamics have been conducted for other pests and the expansion of the species was analyzed with regard to environmental conditions (Burdulaniuk et al., 2025). In terms of topography, a total of 25 sampling points was used to evaluate the heterogeneity of the distribution of terrains. Slopes formed the largest group of sampling locations (10 sites, 40.0%), while hills and lowland constituted other two groups (7 sites, 28.0% and 4 sites, 16.0%,

respectively). Moreover, the flat land was represented by 4 sampling points (16.0%). Consequently, it can be stated that 68% of the sampling points were situated on slopes or hills; consequently, the monitoring system was utilized in most cases on vineyards established on sloping or high places. Thus, it can be stated that the investigated vineyards were located in a different type of landscape, which confirms their non-uniformity in terms of geographical features. In addition, an evident difference in grapevine cultivars was also noticed. The variety Vranç was present at many sampling points, while the varieties Cardinal, Rizling, Merlot, Zhamet, Muscat Hamburg, Moldavka, Black Magic, Prokupë, Chardonnay and other cultivars were noted. Therefore, the sampling network constituted considerable variation in terms of environmental situation and plant host varieties.

The chart in Figure 9 illustrates the temporal trends of the total number of individuals for the period between 2023 and 2025. It should be noted that the empirical support for these trends is based on 25 georeferenced sampling locations. Nevertheless, the trends shown in this paper are averages of four different locations: Rahovec, Deshkidov, Hamovc and Oterush. It is clear that the differences in the number of adult individuals recorded for the four locations is significant, both in terms of the total number of individuals recorded and the temporal trends. It is important to note that the highest number of individuals is recorded for the Rahovec location for each of the three years. In comparison with Rahovec, Hamovc locality has a considerably lower total value and considerably lower variability than Rahovec.

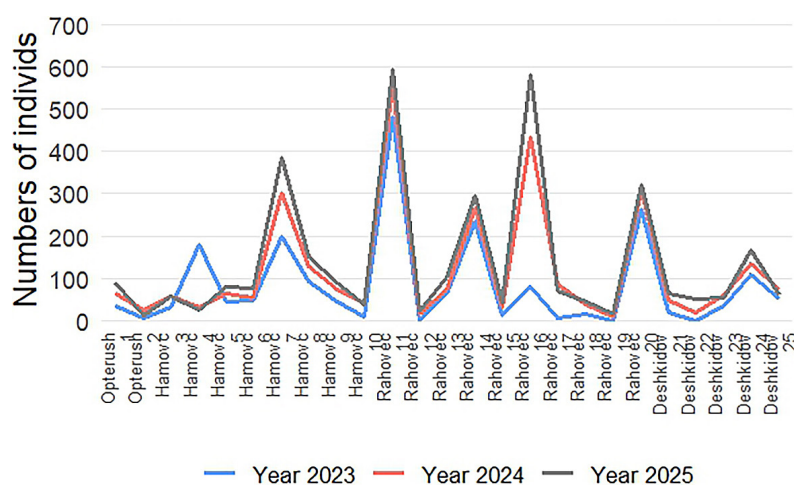


Figure 9. Annual comparison of *Scaphoideus titanus* individual counts recorded at 25 georeferenced sampling locations distributed across four distinct localities within the Rahovec region

It is evident that both sampling sites 11 and 16 which represented two of the highest adult population density levels from 25 monitored sites were located in lowlands. This implies that the lowland vineyards might have been conducive for attracting insects. However, because only two lowland sites showed the highest adult populations, this pattern should be interpreted as an observed spatial association rather than evidence of a direct topographic effect. Apart from topography, it seems that vineyard attributes may play an important role in determining adult population size. Vineyards 11 and 16 are mainly cultivated by the Vranac grapevine cultivar, which is commonly found throughout the Rahovec region and is known for its dense foliage with developed perennial wood. As both high abundance vineyards contained mostly Vranac grapevine cultivar, there might exist some relationship between the characteristics of cultivar associated vineyards and the abundance of adults. However, because no experiments were conducted comparing this particular cultivar to other grapevine cultivars under controlled conditions, no cause effect relationship can be concluded from the current research.

CONCLUSIONS

This study represents the first comprehensive multi-year investigation into the population trends and spatial distribution patterns of *Scaphoideus titanus* within a key viticulture area of Kosovo. The three-year monitoring program confirmed the established presence and increasing abundance of *Scaphoideus titanus* in Kosovo vineyards. Adult populations showed a clear interannual increase with the highest densities recorded in 2025 and particularly pronounced abundance in the Rahovec viticultural locality. Spatial variation in adult abundance was also evident among monitoring sites with higher populations generally associated with valley locations and favorable local microclimatic and vineyard conditions. The population trends observed along with the statistically significant seasonal change in temperature demonstrate that the warmer late spring and summer season is correlated with higher activity of *S. titanus* adults. Nevertheless, the non-significant interannual temperature effect demonstrates that the temperature change cannot be treated as an established factor responsible for the interannual population growth. These findings highlight the

need for continued systematic monitoring of *S. titanus* in Kosovo vineyards and for early detection of population increases to support timely integrated pest management approaches. Further studies are recommended to quantify the factors driving its spatial and temporal distribution.

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