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Seasonal and Daily Movement of *Scaphoideus titanus* Ball (Homoptera: Cicadellidae)

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ABSTRACT Seasonal and daily flight patterns of *Scaphoideus titanus* Ball were investigated in northern Italy, throughout a 3-yr period, using yellow sticky traps placed in an experimental vineyard. Capture data were also analyzed in relation to temperature and relative humidity values. The leafhopper was found to be more active from 1800 to 0800 hours, whereas little movement occurred during high light intensity hours. Although the sex ratio was always male biased, no difference in flight periodicity was found between genders. The seasonal flight peak occurred each year in different periods, ranging from the end of June to the beginning of July, depending on mean temperature values. Daily capture increases were correlated with daily minimum and maximum temperatures and were negatively correlated with maximum values of relative humidity. As a result, this species could be crepuscular or nocturnal, and a bimodal flight periodicity is likely.

KEY WORDS grapevine, nearctic leafhopper, phytoplasma vector, flight activity

THE NEARCTIC LEAFHOPPER *Scaphoideus titanus* Ball, which was introduced to Europe in the 1950s, is now widespread in northern Portugal (Quartau et al. 2001), northern Spain, southern France, Italy, Switzerland, Slovenia, and Croatia (Boudon-Padieu 2000), and its presence has recently been reported in Serbia (Duduk et al. 2003). It lives only on grapevines (*Vitis* spp.) and is univoltine. In northern Italy, adults occur from the middle of June to the beginning of October. Eggs are laid under the bark of 2-yr-old wood, where they overwinter (Vidano 1964).

This species is of great economic importance, because it is known to be the vector of Flavescence dorée, a persistent disease caused by phytoplasmas of the 16Sr-V group, which is considered the most threatening among grapevine yellow diseases in Europe (Boudon-Padieu 2003). Phytoplasma acquisition is made by third-instar nymphs feeding on infected plants, and after a latency period lasting from 28 to 35 d, transmission to healthy grapevines is made by adults, who retain infectivity throughout their life (Schvester et al. 1969). To avoid the spread of disease, compulsory measures such as chemical pest management and removal of infected plants are often applied.

Despite its importance, little is known about *S. titanus* apart from its biology and disease transmission patterns. Some information on spatial distribution (Bosco et al. 1997), population dynamics (Bernard and Du Fretay 1988), and seasonal adult occurrence (Lessio et al. 2003) is available, but other aspects of its behavior such as daily flight activity and influence of temperature and relative humidity on movement behavior were never investigated. Studies of daily movement are known for other vectors such as *Frankliniella occidentalis* (Pergande) (Pearsall 2002), *Circulifer hematoceps* (Mulsant et Rey) (Kersting and Baspinar 1995), *Paraphlesius irroratus* (Say) (Larsen and Whalon 1987), *Bemisia tabaci* (Gennadius) (Blackmer and Byrne 1993), and aphids (Wiktelius 1981). The influence of temperature on movement behavior and the occurrence of temperature thresholds for the initiation of flight have been studied for some leafhoppers such as *Graphocephala atropunctata* (Signoret), a vector of grapevine Pierce's disease (Feil et al. 2000). The objectives of this research were to investigate the seasonal and daily flight behavior of *S. titanus* in northern Italy and to determine if and how its flight activity is influenced by temperature and relative humidity.

Materials and Methods

Field studies were carried out from 2001 to 2003 at Grugliasco (location 45°03′ N, 7°35′ E, 110 m above sea level), in the Faculty of Agriculture of the University of Turin. A 20-yr-old experimental vineyard was chosen: it had an area of 1,555 m^2 and was composed of 18 rows of different vine varieties, for a total of 720 plants. Compass orientation of rows was SE-NW. The vineyard was surrounded by orchards (apple, pear, and stone fruit trees), turfgrass, and other vegetation. No other vineyards were present, and other vine-growing

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Table 1. Sunrise and sunset time, day length, and twilight duration during the max flight period of *S. titanus*

Day of year	Sunrise	Sunset	Day length		Twilight duration	
			h	min	h	min
1 July	0545	2121	15	36	0	37
1 Aug.	0613	2059	14	46	0	34
1 Sept.	0650	2010	13	20	0	30

Location: Grugliasco, Italy (45°03′ N, 7°35′ E; GMT + 1 h).
Beck (1968), Nautica Online (2003).

Table 2. Seasonal presence of *S. titanus* nymphs and adults (means ± SEM) and observed sex ratio (M/F) in the experimental vineyard

Year	Nymphs[a]	Adults trapped[b]		Adult sex ratio
		Males	Females	
2001	0.145 ± 0.0422	23.6 ± 7.2	9.1 ± 3.0	2.6
2002	0.155 ± 0.0454	36.1 ± 8.2	9.9 ± 2.3	3.6
2003	0.355 ± 0.0743	60.1 ± 9.9	15.0 ± 2.5	4.0

[a] Data are nymphs per leaf from one count on 200 leaves at mid-May.

[b] Data are adults per trap from counts on 16 yellow sticky traps throughout all the season.

areas were at least 10 km away. No insecticides were used within the vineyard.

Yellow sticky traps (TEMO-O-CID; Kollant, Verona, Italy) made of rectangular-shaped plastic panels, 40 cm in length and 25 cm in width, were used to monitor *S. titanus* flight periodicity. Yellow was chosen because it is known to be attractive to leafhoppers, although we have investigated the attractiveness of other colors (Lessio and Alma 2004). The yellow shade was 100 by 100 according to Scotti (1993), and reflectance was 95% between 200 and 480 nm. Traps were coated with glue on both surfaces.

To predict the beginning of the flight period, preliminary samplings were made every year by counting nymphs on five leaves from each of 40 randomly selected plants. We chose leaves close to the rootstock, because eggs are laid under the bark of 2-yr-old wood, thus lower shoots are the first to be colonized by nymphs. Counts were done during the middle of May, which is when first-instar nymphs in northern Italy appear. Traps were placed ≈45 d later to ensure the capture of adults (Vidano 1964).

We assessed daily and seasonal flight activity using sticky panels placed vertically on vine rows and fastened to the wire following the row surface. We set 16 traps in a diagonal cross-pattern, at 1 m height within the vine canopy. Trap number was decided according to Nestel and Klein (1995). Sampling was done daily, 5 d/wk, from the beginning of July to the end of September on all traps. Each day we sampled every 2 h from 0800 to 1800 hours (GMT + 1 h). Counts lasted from 20 to 30 min. Within this period, daylength ranged from 15 h 36 min on 1 July to 13 h 20 min on 1 September, while twilight duration varied from 37 to 30 min (Table 1, Nautica Online 2003).

Specimens were dotted on each trap with a permanent black marker, and the date and time of counting was noted; thus, the same insect was not counted twice. To avoid loss of attractiveness or stickiness, traps were immediately changed after heavy rain or when covered by insects. Generally, replacement occurred approximately every 10 d. Removed traps were brought to the laboratory, where *S. titanus* individuals were identified, counted, and sexed by observing external gonapophyses through a 45× stereomicroscope.

Irradiation, temperature, and relative humidity data were taken from a nearby meteorological station.

To assess the influence of climate on *S. titanus* flight activity, minimum and maximum temperature and relative humidity values were plotted against daily *S. titanus* captures. We chose to analyze only captures for the 3–4 wk that corresponded to the peak flight period to avoid mistaking a natural decline of population with a decrease of flight activity.

Trapped insect data were analyzed using SigmaStat 2.0 statistical software (Jandel Scientific Software 1995). Before analysis, raw data of mean captures per trap were square root transformed. A one-way analysis of variance (ANOVA) followed by a Tukey test for separation of means was performed on captures at different times of the day. We pooled daily captures of all traps and considered each day of sampling as a single replication. Model I linear regression was performed between number of trapped insects per day and minimum and maximum values of temperature and relative humidity (Sokal and Rohlf 1995).

Results

Scaphoideus titanus juveniles were generally found during the middle of May (Table 2). The first adults were detected during mid-July in the first 2 yr, whereas in 2003, they began to fly at the end of June. The flight peaks occurred on 1 August 2001, 16 August 2002, and 8 July 2003 (Fig. 1). The total number of leafhoppers caught was 523 in 2001, 736 in 2002 and 1,203 in 2003. The sex ratios were always male biased (Table 2). Males occurred mainly in the first part of the season, whereas later, many more females were detected.

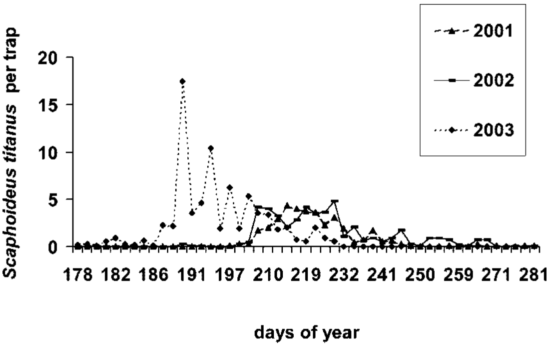

Fig. 1. Seasonal flight activity of *S. titanus* Ball.

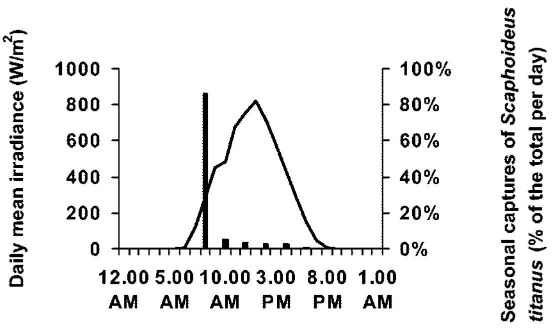

Fig. 2. Daily flight activity of *S. titanus* Ball (bars) and hourly solar radiation (line) during 2001. First bar of morning is from 1800 to 0800 hours.

Study of daily flight activity occurred from 30 July to 24 August 2001, from 22 July to 9 August 2002, and from 7 to 25 July 2003. Results show how captures were significantly higher during night (1800–0800 hours) for both males and females and that 78–93% of the total caught per day were captured at those hours (Figs. 2–4; Table 3). In contrast, no differences were found among captures during daytime from 1000 to 1800 hours, when the number of trapped insects was always below 10% of the total.

Mean temperatures recorded in July and August were 23.8 and 24.8°C in 2001, 22.5 and 21.3°C in 2002, and 26.3 and 27.2°C in 2003. *S. titanus* flight activity was influenced by temperature fluctuations. Daily captures recorded within the maximum flight period increased along with the minimum temperatures; in this period of time, minimum temperature values ranged from 12.1 to 24.3°C, and the maximum number of captured leafhoppers occurred in correspondence with minimum temperature value of 22°C (Fig. 5). Although maximum daily temperatures also affected leafhopper flight activity, the latter was always very low in the hottest hours of the day. Maximum temperature values ranged from 18.8 to 37.0°C (Fig. 6).

No relationship was found between minimum relative humidity values (range, 17–79%) and captures of *S. titanus* adults (Fig. 7). However, maximum relative humidity values (63–99%) were negatively correlated with captures (Fig. 8).

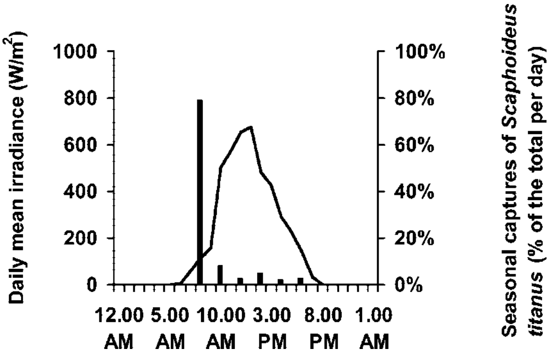

Fig. 3. Daily flight activity of *S. titanus* Ball (bars) and hourly solar radiation (line) during 2002. First bar of morning is from 1800 to 0800 hours.

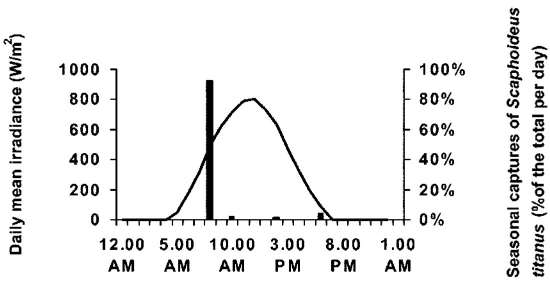

Fig. 4. Daily flight activity of *S. titanus* Ball (bars) and hourly solar radiation (line) during 2003. First bar of morning is from 1800 to 0800 hours.

Discussion

This research shows that *S. titanus* flight activity is greater between late afternoon and early morning, whereas very little movement occurs during high light intensity hours. Locomotory behaviors of insects such as flight are defined as unimodal, bimodal, trimodal, etc., depending on the presence of one or more activity peaks within a 24-h period (Beck 1968). Crepuscular flight activity has been shown for many Auchenorrhyncha such as *P. irroratus* (Larsen and Whalon 1987) and *Dalbulus* spp. (Taylor et al. 1993). *C. haematoceps* also has a unimodal pattern of flight at 1930 hours in Turkey (Kersting and Baspinar 1995), whereas *Graminella nigrifrons* (Forbes) is more likely to fly at dawn and dusk (Rodriguez et al. 1992). Many delphacids and cicadellids associated with rice showed a bimodal flight. Major activity occurs at sunset and is entrained by moon phases (Perfect and Cook 1982). Few species of leafhoppers and planthoppers seem to be more active during daytime. However, the three-cornered alfalfa hopper, *Spissistilus festinus* (Say), has a diurnal movement pattern. Its maximum activity occurs at 1400 hours; however, it is not a well-defined unimodal flight (Johnson and Mueller

Table 3. Statistics of captures of *S. titanus* males and females (means ± SEM) at different times of the day

Time of day[a]	*S. titanus* males (mean ± SEM)	*S. titanus* females (mean ± SEM)
0800	1.528 ± 0.226A	0.274 ± 0.0352a
1000	0.0737 ± 0.0203B	0.0125 ± 0.00472b
1200	0.0175 ± 0.00857B	0.0119 ± 0.00888b
1400	0.0407 ± 0.0131B	0.00758 ± 0.00426b
1600	0.0175 ± 0.00962B	0.00833 ± 0.00472b
1800	0.0478 ± 0.0135B	0.0119 ± 0.00482b

[a] GMT + 1 h.

Data are pooled daily captures per trap of the 3-yr study period (n = 50). Same letters (capital for males, small for females) indicate no statistical difference between captures at different times of the day (one-way ANOVA; Jandel Scientific Software 1995). Raw data were square root-transformed before analysis (Sokal and Rohlf 1995). Males: $F = 105.384$; df = 5, 294; $P < 0.001$. Females: $F = 76.076$; df = 5, 294; $P < 0.001$.

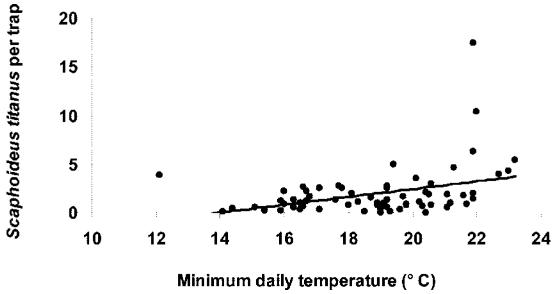

Fig. 5. Effect of minimum daily values of temperature on the flight activity of *S. titanus* Ball in the 3-yr study period. Data (mean ± SEM): insects per trap (y) = 1.939 ± 0.309; minimum temperature (x) = 18.75 ± 0.285. Model I linear regression (n = 69; significance for $P < 0.05$): y = −0.884 + 0.624x (R^2 = 0.146, P = 0.001).

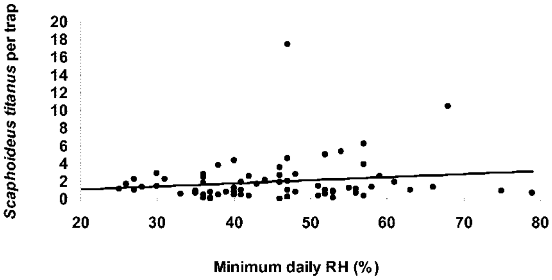

Fig. 7. Effect of minimum daily values of relative humidity (RH) on the flight activity of *S. titanus* Ball in the 3-yr study period. Data (mean ± SEM): insects per trap (y) = 1.939 ± 0.309; minimum RH (x) = 44.870 ± 1.437. Model I linear regression (n = 69; significance for $P < 0.05$): y = 0.797 + 0.009x (R^2 = 0.025, P = 0.189).

1990). Regarding *S. titanus*, further studies should be conducted to determine the exact moment of day for flight. Because many specimens (in some cases up to 20%) were still alive when counted at 0800 hours on sticky traps, it is likely that some activity occurs in the early morning. However, reports on the behavior of more or less closely related species suggest how activity could occur at dusk. As for exogenous and endogenous entrainment (Saunders 1976), laboratory studies will be required to determine whether *S. titanus* flight periodicity is caused by a free-running circadian clock or whether it is totally entrained by photoperiod.

Differences in daily catches of *S. titanus* could also be explained by different responses to color attraction at different times of the day. Visual sensitivity patterns could change along with light intensity, as shown for the green lacewing *Chysoperla carnea* (Stephens) (Kral and Stelzl 1998).

Photoperiodic entrainment of flight could also indirectly influence insect dispersal. According to Taylor (1974), crepuscular species that move when the boundary layer (a layer of air near the ground where insects are able to control their flight) is closer to the ground are less likely to be carried by the wind because atmospheric lift is minimal at night, and their dispersal depends therefore on their own active flight capabilities. Drake and Farrow (1988) suggest how nocturnal migration occurs mainly among large insects, whereas microinsects are more likely to move during daytime because they rely on atmospherical lift. Because *S. titanus* is not so likely to fly above 2.50 m and its movement patterns are quite restricted to the canopy (Lessio and Alma 2004), its low dispersal capabilities could be related to a crepuscular behavior.

Scaphoideus titanus males and females did not differ in daily flight periodicity. Both genders showed an increased flight activity between 1900 and 0800 hours and little movement during the rest of the day. Sex ratios of daily captures was always male biased, but this is because of the fact that males have a higher dispersal rate; thus, they are more likely to be trapped on sticky cards (Lessio et al. 2003, Lessio and Alma 2004), and a higher activity of males is often reported for many other species of Auchenorrhyncha (Johnson and Mueller 1990, Rodriguez et al. 1992, Kersting and Baspinar, 1995).

Seasonal and daily flight of *S. titanus* was partially influenced by temperature. In Summer 2003, mean temperatures were 3–6° higher than the prior 2 yr, and

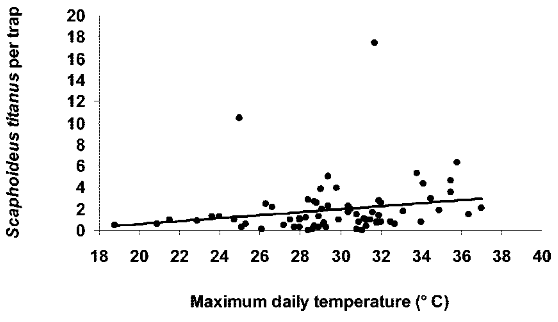

Fig. 6. Effect of maximum daily values of temperature on the flight activity of *S. titanus* Ball in the 3-yr study period. Data (mean ± SEM): insects per trap (y) = 1.939 ± 0.309; maximum temperature (x) = 29.622 ± 0.445. Model I linear regression (n = 69; significance for $P < 0.05$): y = −0.282 + 0.05x (R^2 = 0.0726, P = 0.025).

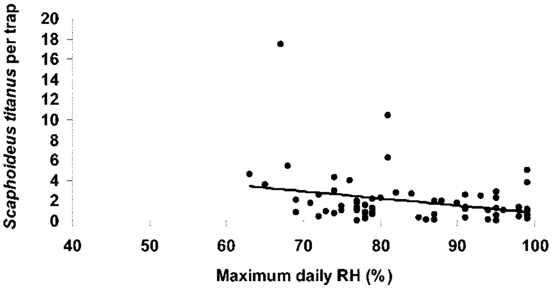

Fig. 8. Effect of maximum daily values of relative humidity (RH) on the flight activity of *S. titanus* Ball in the 3-yr study period. Data (mean ± SEM): insects per trap (y) = 1.939 ± 0.309; maximum RH (x) = 84.043 ± 1.266. Model I linear regression (n = 69; significance for $P < 0.05$): y = 2.888 − 0.01x (R^2 = 0.0921, P = 0.011).

this could have caused the 2- to 3-wk advance in the flight peak. However, this could be simply because of an advanced development of adults. Movement was higher when daily minimum and maximum temperatures increased, but no thresholds for flight were detected. Among leafhoppers, a threshold of 14°C for take off was detected for *G. atropunctata* in California (Feil et al. 2000). However, *G. nigrifrons* is more likely to move when average temperatures at dusk are above 18°C (Rodriguez et al. 1992). Maximum temperature values also influenced *S. titanus* flight activity. However, because flight occurs mainly between late afternoon and morning, an increase in temperature could effectively determine a positive flight response, but not during the hottest hours of the day. A similar pattern was found for *C. haematoceps,* whose daily flight behavior is not entrained by temperature (Kersting and Baspinar 1995). Therefore, it is more likely that *S. titanus* daily flight activity is only secondarily entrained by temperature and depends mainly on the photoperiod, although a mechanism of temperature compensation (Saunders 1973) could be possible.

Our results suggest that high relative humidity could result in a decrease in *S. titanus* flight activity. However this could be because of the fact that an increase in relative humidity is the consequence of a decrease of atmospheric motion. Little information is available in literature about the influence of relative humidity on flight behavior, and Auchenorrhyncha have not been investigated so far. Zhang and Shipp (1998) showed how an increase of vapor pressure deficit, which is negatively related to relative humidity, causes an increase in flight activity of the hemipteran *Orius insidiosus* (Say), and they suggest how an increase in take-off because of a decrease in relative humidity could be a means of avoiding desiccation by seeking a moister environment.

Acknowledgments

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