Three-year Dynamics of Common Ash Defoliation and Crown Condition in the Focus of Black Sawfly *Tomostethus nigritus* F. (Hymenoptera: Tenthredinidae)

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Meshkova, V., Kukina, O., Zinchenko, O., Davydenko, K., 2016. Three-year Dynamics of Common Ash Defoliation and Crown Condition in the Focus of Black Sawfly *Tomostethus nigritus* F. (Hymenoptera: Tenthredinidae). *Baltic Forestry* 23(1): 303-308.

Abstract

Black sawfly (*Tomostethus nigritus*), the foliage browsing pest of common ash (*Fraxinus excelsior*) after several years of depression was registered in forest stands, forest shelter belts and urban ornamental stands of the East Ukraine. The aim of this research was to reveal the peculiarities of ash defoliation by black sawfly during three years of outbreak and to recognize the changes in health condition of defoliated trees. Research was carried out for 2013–2015 in Molodezhny park of Kharkiv (50°00' N; 36°25' E) (Ukraine, Forest-steppe natural zone) in two groups of common ash trees (forest belt and compact stand). For each labeled tree, defoliation of the whole crown and separately of upper, middle and lower layers, outer and inner parts of crown was assessed in June of 2013, 2014 and 2015, and additionally in July 2015. Health condition of each labeled tree was assessed in June 2013 and July 2015. Defoliation of common ash trees did not significantly differ in 2013 and 2014. It almost twice increased in 2015 and in average exceeded 90 %. Dependence of defoliation from crown layer, crown part (outer or inner) or tree diameter was not proved statistically, but correlation analysis shows the better health condition of larger trees. The fast recovery of ash crowns after severe damage by black sawfly in 2015 can be explained by favorable weather conditions. Analysis of ash trees distribution by categories of health condition show the improvement of their health after three years of foliage damage by ash sawfly, but forest stand continues to be weakened. Considerable parts of the trees, which belonged to the 2^{nd}, 3^{rd} and 4^{th} categories of health condition in 2013, changed it by one-three grades. Totally 50 % of trees did not change the category of health condition, 35.3 % of trees improved it and 14.7% worsened it.

Key words: black sawfly (*Tomostethus nigritus*), common ash (*Fraxinus excelsior*); defoliation, crown condition.

Introduction

Black sawfly (*Tomostethus nigritus*) is known as common ash (*Fraxinus excelsior* L.) pest in Russia (Belova 1987), Norway (Austarä 1991), Croatia (Matošević et al. 2002), Czech Republic (Mrkva 1965, Holuša, Drápela 2004), Serbia (Glavendekić and Mirić 2009, 2011), Italy (Mitali 2012).

In the East part of Ukraine black sawfly caused a short-time outbreak in 2002 (Meshkova and Davydenko 2013) and after several years of depression severe defoliation of common ash by this pest was registered in forest stands, forest shelter belts and urban ornamental stands in Donetsk (Popov 2009) and Kharkov regions (Meshkova et al. 2013, Davydenko and Meshkova 2014, Kukina et al. 2014, Zinchenko and Kukina 2015) of Ukraine.

Chemical forest protective measures should be based on ecological and economic principals to minimize pesticide usage by tapping the full potential of all preventive methods. The threat for forest from the same pest exists only in certain regions, forest stands and under certain weather conditions. Therefore it is important to know the effect of foliage browsing insects on tree condition and growth in every region. In connection with it, numerical evaluation of injuriousness of foliage browsing insects must include assessment the defoliation (which characterizes tree resistance to damage) and further tree response to damage (the change of health condition, increment and mortality, which characterize tree tolerance to damage) (Meshkova 2013).

Biological peculiarities of black sawfly and its impact on tree growth and health condition are poorly known, especially for the East of Ukraine. Therefore such studies were started in green stands of Kharkiv (Ukraine), where larvae of black sawfly damage the crowns of common ash for three years successively (2013–2015). Biological peculiarities of this pest in the region were specified in the East Ukraine (Zinchenko and Kukina 2015). It was proved by these authors, that black sawfly is univoltine monophag, which damages only common ash. The beginning of black sawfly swarming in the East Ukraine coincides with the beginning of common ash foliage development (April, 19–25). Mass swarming started April 24, April 28 and April 26 in 2013, 2014 and 2015, respectively (Zinchenko and Kukina 2015). The eggs of ash black sawfly develop about 10 – 13 days and the first larvae appear at the beginning of May, pass 5 instars and complete feeding at the third decade of May (Zinchenko and Kukina 2015). The larvae form cocoons from the end of May to the beginning of June in forest litter under the crowns. The first pupae of black sawfly appeared in 2013, 2014 and 2015 on April 4–6, 7–9 and 12–15 respectively (Zinchenko and Kukina 2015).

To predict the threat to stands from black sawfly it is necessary to study, which stands and trees are the most defoliated by black sawfly, and how such damage affects the health condition of the trees.

Therefore the aim of this research was to reveal the peculiarities of ash defoliation by black sawfly during three years of outbreak of the pest and to recognize the changes in health condition of defoliated trees.

Materials and methods

Investigations were carried out in 2013 – 2015 in Molodezhny park of Kharkiv (50°00' N; 36°25' E) (Ukraine, Forest-steppe natural zone). Besides common ash (*Fraxinus excelsior* L.), the trees of *F. pennsylvanica* var. *lanceolata* Borkh., *Betula pendula* Roth., *Aesculus hippocastanum* L., *Sorbus aucuparia* L., *Ulmus laevis* Pall., *Acer platanoides* L,. *Tilia cordata* Mill. and *Quercus robur* L. grow in this park. From these tree species only common ash was damaged by black sawfly. Therefore only trees of common ash were labeled in 2013 to monitor their defoliation and health condition.

Two groups of common ash trees were monitored: 25 trees in forest belt (alley) and 43 trees in rather compact stand (curtain).

Diameter at breast height was measured in 2013. Defoliation of each tree was assessed visually up to 5 % at the beginning of June 2013, 2014 and 2015, that is after the end of larvae feeding and their descent from the crown to the litter (Zinchenko and Kukina 2015). Defoliation of upper, middle and lower crown layer, as well as defoliation of outer (peripheral) and inner (central) parts of crown were additionally assessed at the same dates.

In July, 2015 additional assessment of defoliation (for the whole tree) and crown condition was carried out to recognize the crown recover, taking into account the period of ash shoot growth (Gordienko et al. 1996).

Category of tree health condition was assessed in June 2013 (the first year of black sawfly outbreak) and in July 2015. Category of health condition was evaluated on a range of visual characteristics (crown density and color, the presence and proportion of dead branches in the crown etc.) according to "Sanitary rules in the forests of Ukraine" (Sanitary rules in the forests of Ukraine 1995). Each tree was referred to one of six categories of health condition (1st – healthy; 2nd – weakened; 3rd – severely weakened; 4th – drying; 5th – recently died; 6th – died over year ago). Index of health condition for forest stand was calculated as mean weighted from trees number of each category of health condition.

Data on air temperature and precipitation for 2013 – 2015 and mean for 1981 – 2010 were taken from meteorological station Kharkiv (49°90' N; 36°30' E).

The statistical analyses included calculation the mean and standard error of defoliation, one-way analysis of variance (ANOVA) and correlation between tree diameter, defoliation and category of health condition (StatSoft Software, Ver. 7)

Results

In the both plots (forest belt and compact stand) defoliation of common ash trees in 2015 was significantly higher than in 2013 and 2014 (Figure 1, 2). In 2013 averaged defoliation amounted 43 and 53.1 %, in 2014 – 57 and 41.4 %, and in 2015 – 93 and 95.8 % in forest belt and compact stand respectively. However, in the both stands both undamaged and totally defoliated trees could be found every year.

Differences in defoliation in forest belt in 2013 and 2014 were not significant ($F_{calc.}$ = 3.1; $F_{0.05}$ = 4,0), while in 2015 defoliation significantly exceeded meanings of previous years ($F_{calc.}$ = 14.4; $F_{0,05}$ = 3.2). Similarly, any significant differences were revealed for compact stand defoliation in 2013 and 2014, but in 2015 it was significantly greater than in previous years ($F_{calc.}$ = 112.1; $F_{0.05}$ = 4.0).

Trend to increase defoliation from 2013 to 2015 is seen for all crown layers, in the outer and inner parts of crown (see Figure 1, 2).

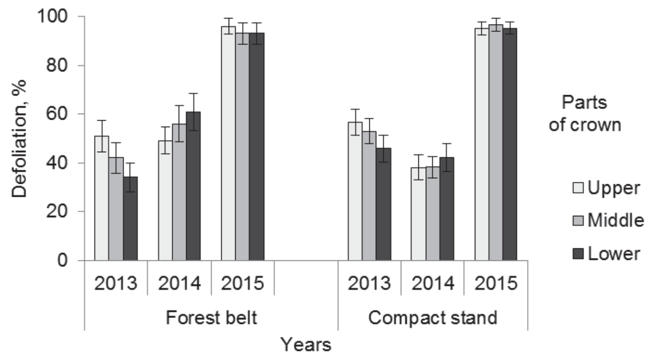

Figure 1. Mean defoliation of different crown layers of common ash in 2013–2015 in forest belt and compact stand (bars mean standard error)

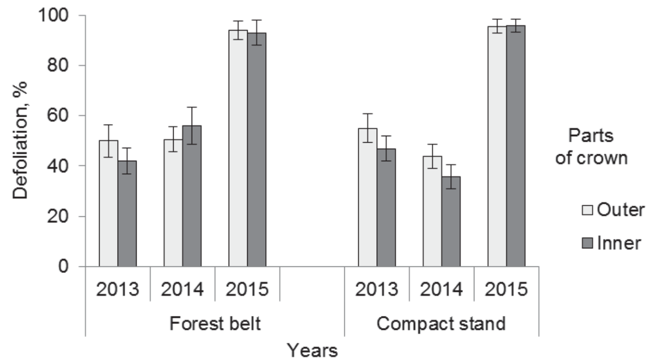

Figure 2. Mean defoliation of common ash in central and peripheral parts of the crown in 2013–2015 in forest belt and compact stand (bars mean standard error)

In 2013 both in forest belt and compact stand the trend was revealed for defoliation decrease from upper to lower crown layer (see Figure 1). In 2014 the trend was reciprocal when defoliation increased from upper to lower crown layer. In 2015 defoliation of all crown layers was about the same, and the difference was insignificant (P > 0.1) for different crown layers in forest belt ($F_{calc.}$ = 1.9; $F_{0.05}$ =3.1) and in compact stand ($F_{calc.}$ = 1.26; $F_{0.05}$ = 3.1).

Defoliation of outer part of ash crown was significantly higher than inner part of crown only in forest belt in 2013 ($F_{calc.}$ = 5.2; $F_{0,05}$ = 4.0). In other years defoliation of inner and outer parts of crown did not differ statistically in forest belt ($F_{calc.}$ = 0.38; $F_{0.05}$ =4.0) and in compact stand ($F_{calc.}$ = 1.1; $F_{0.05}$ = 4.0) (see Figure 2).

Ash stem diameter at breast height (1.3 m) amounted 40 – 80 cm in forest belt and 30 – 70 cm in compact stand. Mean defoliation for groups of trees with different diameter (by 10 cm classes) was evaluated (Figure 3).

Both in the forest belt and in compact stand the trend can be seen in 2013 and 2014 to decrease defoliation with increase of tree diameter. However, statistically this trend is not proved (*P* > 0.1). In 2015 defoliation of trees from all diameter classes approached 100 %, and even trend to relation between tree diameter and defoliation was not revealed.

Comparison of mean ash defoliation for all years of investigation show significant differences between defoliation in forest belt and in compact stand only in 2014 (P < 0.05, $F_{calc.}$ = 4.8; $F_{0.05}$ = 4.0). In 2013 and in both assessments of 2015, the differences between mean defoliation of ash trees in forest belt and in compact stand were not significant (P > 0.1) (Figure 4).

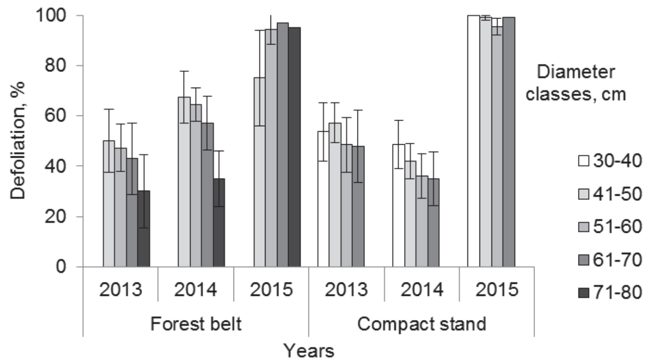

Figure 3. Mean defoliation of common ash of different diameter in 2013–2015 in forest belt and compact stand (bars mean standard error)

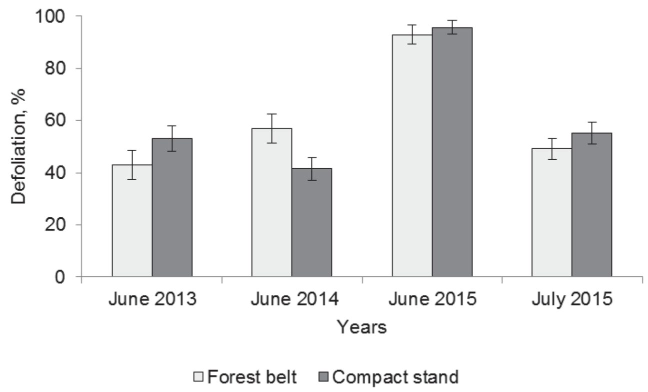

Figure 4. Mean defoliation of common ash in forest belt and compact stand at different asessment datas (bars mean standard error)

Comparison of defoliation assessment data from June and July 2015 shows that ash defoliation has decreased for one month by 1.9 and 1.7 times in forest belt (F_{calc} = 68.9; $F_{0.05}$ = 4.1) and in compact stand ($F_{calc.}$ = 66.6; $F_{0.05}$ = 4.0) respectively due to crown recover. Difference between defoliation for these two dates is significant (P < 0.0001).

Analysis of weather conditions in 2013 and 2014 shows that air temperature of April – May exceeded the long-term data, and in 2015 notable excess of the long-term data (per 2.1 °C) was registered only in June, when development of black sawfly has already completed (Figure 5).

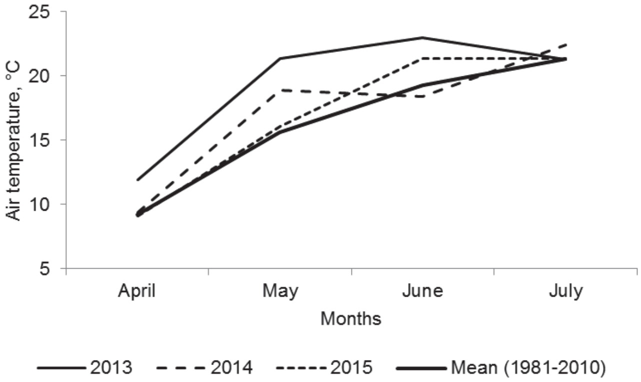

Figure 5. Air temperature of April-July in 2013–2015 and long-term data (meteorological station Kharkiv)

However, precipitation in June 2014 exceeded the long-term data 2.25 times, and in July 2014 was 1.5 times less than by the long-term data (Figure 6).

Precipitations in June 2015 exceeded the long-term data 1.2 times, and in July in 1.75 times, which together with high temperature was favorable for foliage recover (see Figure 6).

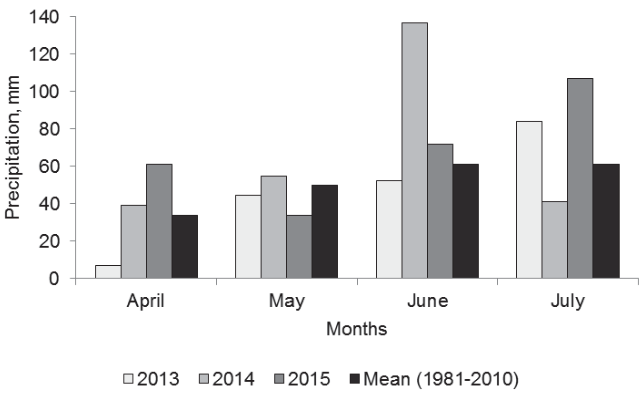

Figure 6. Precipitation in 2013–2015 and long-term data (meteorological station Kharkiv)

Taking into account the lack of significant difference between ash defoliation in forest belt and compact stand, the health condition was analyzed in pooled data.

Assessment of 2013 show (Figure 7) that the trees of the 2nd (weakened) and the 3rd (severely weakened) categories of health condition dominated (39.1 and 32.8 % respectively), and weighted index of health condition for forest stand amounted 2.47.

In 2015, after three years of annual crown damage by black sawfly, the weighted index of health condition defoliation has decreased slightly (to 2.27), i.e. tree condition has become better, and trees' distribution by the categories of health condition has considerably changed (see Figure 7).

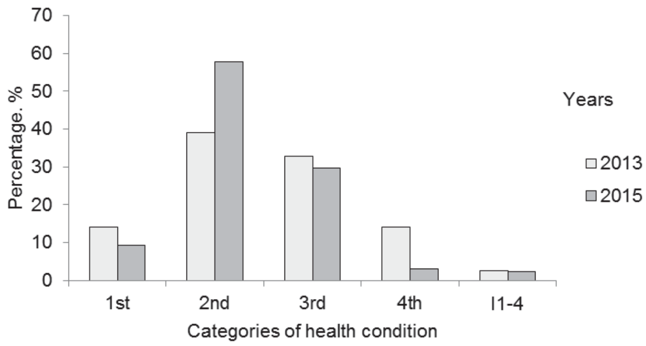

Figure 7. Distribution of ash trees by categories of health condition in 2013 and 2015

As every tree was marked, it was possible to determine how many of them have not change their health condition for three years, improved or worsened it. Totally, 50 % of all trees remained the same category of health condition while the 35.3 % of trees improved their category and 14.7% worsened it (Table 1).

Table 1. Evaluation of trees number, which have not changed, have improved or worsened their health condition for 2013–2015

Health condition in 2013*	Changes in 2015, %**		
	not changed	improved	worsened
1st (9)	11.1±31.4 (1)	–	88.9±11.1 (8)
2nd (27)	81.5±8.3 (22)	11.1± 18.1 (3)	7.4±18.5 (2)
3rd (23)	39.1±16.3 (9)	60.9±13.0 (14)	–
4th (9)	22.2±29.4 (2)	77.8±15.7 (7)	–
Total (68)	50.0±6.1 (34)	35.3±5.8 (24)	14.7±4.3 (10)

* – number of trees in 2013 is given in brackets
** – number of trees in 2015 is given in brackets

The most part of trees (88.9% of trees), which were healthy (the 1st category of health condition) in 2013, have worsened health condition in 2015. The most part of trees (81.5% of trees), which were weakened (the 2nd category) in 2013, have not changed their health condition in 2015. The most part of trees (60.9% of trees), which were severely weakened (the 3nd category) and the most part of trees (77.8% of trees), which were drying (the 4nd category) in 2013, have improved their health condition (see Table 1).

Correlation analysis was carried out with data on tree defoliation, tree diameter and health condition using pooled data from the both plots (forest belt and compact stand) (n = 68 trees).

A significant negative relationship between the tree diameter and its health condition in 2013 ($r = -0.28 \pm 0.12$; $P < 0.05$) and in July 2015 ($r = -0.35 \pm 0.12$; $P < 0.01$) was proved. It means that the trees of the bigger diameter had the lesser category of health condition, i.e. the better health condition.

A significant positive relationship is proved between the tree category of health condition in 2013 and in July 2015 ($r = 0.35 \pm 0.12$; $P < 0.01$), the tree category of health condition in 2013 and defoliation in 2013 ($r = 0.52 \pm 0.11$; $P < 0.01$), defoliation in 2013 and in 2014 ($r = 0.51 \pm 0.11$; $P < 0.01$).

Discussion and conclusions

Our investigation show, that both in forest belt and in compact stand every year both undamaged and totally defoliated trees were revealed. It can be explained by the fact that leaf tissue quality varied among and within tree individuals, which is proved for different foliage browsing insects, for example, for *Epirrita autumnata* (Henriksson et al., 2003).

Thickness, water and nutritional content differ both among trees and within an individual tree, between illuminated and shaded leaves.

We took into account that adults of black sawfly hatch from pupae, which are located in the forest litter, about the time of ash bud burst. To lay eggs they choose the shoots with enough developed leaves. It was suggested, that such leaves become earlier in the upper and outer parts of crown.

Only in the forest belt in 2013 defoliation of outer part of ash crown was significantly greater than inner part of crown. In other cases our investigations show the absence of common ash crown layer or crown part (outer or inner) influence on foliage damage by black sawfly larvae (see Figures 1 and 2). The trend was revealed for defoliation decrease from upper to lower crown layer in 2013 and for defoliation increased from upper to lower crown layer in 2014. Such trend may be explained by specific influence of neighboring trees on microclimate inside the crowns which affects the rate of shoot growth, foliage quality and larval survival. Respective data on ash phenology and possible influence of neighboring trees would be considered in a separate paper.

We suggested that microclimate in forest belt and in compact stand would influence on ash defoliation by black sawfly. However, the results show the absence of significant differences between two stands in each of years and similar trend to increase of defoliation in 2015 (see Figures 1, 2).

Common ash defoliation caused by black sawfly in 2013 and in 2014 was significantly correlated, but correlation was insignificant for defoliation of these both years with defoliation of 2015. It may be related with peculiarities of outbreak culmination or by other causes which were not studied here.

Both in the forest belt and in compact stand in 2013 and 2014 the dependence of defoliation on tree diameter was not proved statistically (see Figure 3).

Our research shows the fast recover of ash crown after severe damage by black sawfly in 2015 (see Figure 4).

Such intensive recover of crown condition in 2015 can be explained by peculiarities of weather conditions. As it was shown (Zinchenko and Kukina 2015), in 2015 comparing to 2013 and 2014, the larvae of black sawfly started feeding the most early (on April, 29), and completed the most late (on May, 25). Namely that the foliage was the most severally damaged on the beginning of its development brought to active shoot growth from reserve buds.

Ash shoot growth completes in middle July, therefore weather conditions did not promote foliage recover in 2014. In 2015 both air temperature and precipitation exceeded the long-term data in June, when black sawfly development has already completed, which was favorable for foliage recovery (see Figures 5 and 6).

A significant positive relationship was proved between defoliation and category of health condition of ash trees in 2013, as well as between the tree category of health condition in 2013 and in July 2015, that is after crown recovery. It may be the evidence that health condition of the tree is rather stable, and its recovery occurs at favorable conditions.

Analysis of ash trees distribution by categories of health condition shows the improvement of their health after three years of foliage damage by ash sawfly, but stand continues to be weakened (see Figure 7).

Considerable parts of the trees, which belonged to the 2nd, 3rd and 4th categories of health condition in 2013, changed it on one-three grades. Our results demonstrated that no ash tree has died since the last outbreak of black sawfly in 2002. It means that common ash is rather tolerant to foliage damage by ash sawfly.

We have seen the similar situation during outbreak of European pine sawfly (*Neodiprion sertifer* Geoffr. 1785: Hymenoptera: Diprionidae) in Ukraine (Meshkova and Kolenkina 2016). This pest damages needle of Scots pine of previous year in May, when the shoots of current year continues its development. Only those pine trees died, which were damaged not less than 80 % for three years.

The results of this study provide information that may be used in the development the methods of prediction of black sawfly influence on common ash condition and in decision making for integrated control of this pest. At the same time long-term survey must be carried out to recognize the consequences of this pest on ash stands. Peculiarities of microclimate and phenology of ash trees in different parts of stand must be taken into account.

Acknowledgements

This study was supported by the EU RTD Framework Programme COST project FP 1103.

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