The ragweed leaf beetle *Zygogramma suturalis* F. (Coleoptera: Chrysomelidae) in Russia: current distribution, abundance and implication for biological control of common ragweed, *Ambrosia artemisiifolia* L.

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Summary

The ragweed leaf beetle, *Zygogramma suturalis* F. (Coleoptera: Chrysomelidae), was introduced to Russia in 1978 against the common ragweed, *Ambrosia artemisiifolia* L. By 1985, it successfully acclimated and suppressed ragweed in the original release site and several neighbouring fields. However, because of crop rotation, its population density drastically decreased. In 2005 and 2006, we conducted selective quantitative sampling in Southern Russia. The results showed that the ragweed leaf beetle was distributed over an area of about 50,000 km^2 in Krasnodar territory, west of Stavropol' territory and south of Rostov province, i.e. most of the area heavily infested by ragweed in Russia. However, the average *Z. suturalis* population density was very low: approximately 0.001 adults per square metre (m^2) in crop rotations and approximately 0.1 adults/m^2 in more stable habitats, although in a few of the studied plots, up to 2–3 adults/m^2 were recorded. As for common ragweed, average percent cover in crop rotations and in stable habitats was approximately 1% and 40%, correspondingly. A detectable level of host plant damage (≥5%) was recorded only in a few plots. The observed spatial variation of the *Z. suturalis* population density was mostly determined by the host plant abundance. The last was strongly dependent on the stability of the habitat, being much higher in stable habitats. Thus, it is still possible that stable protected field nurseries could be a promising method of *Z. suturalis* propagation for biological control of ragweed in surrounding locations.

Keywords: weeds, biological control, post-release evaluation.

Introduction

Common ragweed, *Ambrosia artemisiifolia* L., is one of the most noxious invasive weeds in Russia infesting agricultural fields, ruderal habitats etc. over more than 60,000 km^2 (Ul'yanova, 2003). In an attempt to control this weed, the ragweed leaf beetle, *Zygogramma suturalis* F., was introduced to Russia from the United States and Canada (Kovalev *et al.*, 1983). In 1978, about 1500 specimens were released in the vicinity of Stavropol'. By 1981, a significant increase in the *Z. suturalis* population density was recorded. In 1983, ragweed at the experimental release site was eliminated, and the ragweed leaf beetle began to spread over surrounding fields (Kovalev *et al.*, 1983). Thus, the initial phase of this introduction was a population explosion with more than a 30-fold yearly increase in number, up to 100,000,000 adults/km^2 in fields and up to 5000 adults/m^2 in aggregations (Kovalev, 1988). In some cases, a 'solitary population wave', i.e. a moving zone of ultra-high population density, was observed (Kovalev, 1988). Following these waves, common ragweed was exterminated locally very quickly, which allows one to expect highly efficient biological control of

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the weed (Kovalev, 1988; Goeden and Andres, 1999). From 1984 to 1986, a number of further releases were made in the south of European Russia and Ukraine, but the population wave was not subsequently observed, possibly because the insects were released in regularly exploited agricultural landscapes but not in special protected sites (Reznik *et al.*, 1994).

Later studies conducted in the area of the first release site have demonstrated that, in crop rotations, *Z. suturalis* population density drastically decreased despite a few patches with insect overcrowding and local weed control (Reznik *et al.*, 1994; Reznik, 1996). In these studies, regular estimations of the ragweed leaf beetle population density were restricted to a limited area in the environs of the initial release site. Now, almost 30 years after the initial release, data on *Z. suturalis* distribution and abundance are still fragmental (Ugryumov *et al.*, 1994; Polovinkina and Yaroshenko, 1999; Os'kin, 2002; Esipenko and Belikova, 2004).

At present, common ragweed invading Central and Western Europe poses a threat to the economy and human health by producing highly allergenic pollen in Austria, France, Italy, Hungary and Switzerland (Wittenberg, 2005). Analysis of the results of unsuccessful projects as well as of successful ones is important in improving the theory of biological control of weeds (Harris, 1993; Stiling, 1993; McFadyen, 1998; Müller-Schärer *et al.*, 2000; Raghu *et al.*, 2006). In addition, the 'planned invasion' of the ragweed leaf beetle can be considered as a model for predicting consequences of 'real' invasions (Ehler, 1998; Fagan *et al.*, 2002).

In 2005–2006, we conducted selective quantitative sampling over the whole area infested by *A. artemisiifolia* in Southern Russia. The aims of this study were to estimate *Z. suturalis* population densities in relation to environmental factors and to evaluate the impact of the phytophage on the targeted weed.

Methods and material

Methods

All studies were conducted between 15 July and 15 August, when *Z. suturalis* adults usually reach peak density (Kovalev *et al.*, 1983). In our earlier investigations (Reznik, 1993), 0.1 m^2 plots were used for exact determination of population densities by counting the beetles and measuring the plants. However, for the broad scale investigations, this method was found to be too time consuming. Later (Reznik *et al.*, 1994), the plant and the insect population densities were visually estimated with a scale of 0 to 5. But for the current study, fast visual estimation was not suitable, considering the low population density of the beetle. Thus, a new method was developed.

Plots with more or less uniform vegetation (particularly, ragweed abundance) separated from other plots by some natural borders (field boundary, road, forest belt etc.) were considered as sampling units. The size of the plot varied from 10 to 15 m^2 (isolated ragweed patches) to many hectares (agricultural fields). Usually, all plots along a randomly selected route were inspected.

For each plot, its square (m^2) and habitat type: agricultural field, field margin or ruderal (mostly roadsides) were recorded. The ragweed characteristics (percent cover and average height) were measured. *Z. suturalis* population density was measured by two methods. First, adults over a given square (one or several randomly selected transects of 1 m width and of total length depended on the size of the plot) were counted, and the mean number of adults per square metre was calculated. Second, sweeping with a standard net (along other randomly selected transects) was made, and the mean number of adults per ten sweeps was recorded. Impact on the targeted weed was evaluated visually by considering the relation (percentage) of the area eaten to primary leaf area. In addition, geographical coordinates of each plot, height above sea level, date of sampling and certain additional data were recorded.

Material

Sampling was conducted from 2005 to 2006 in three main areas of Southern Russia heavily infested with common ragweed: Krasnodar territory, Stavropol' territory and Rostov province (Fig. 1). At nine locations (191 plots, total approximately 6.3 km^2) where the ragweed leaf beetle was relatively abundant, 760 adults were visually counted within 22,434 m^2 of transects, and 885 adults were collected by 6480 sweeps. In addition, a number of occasional records of *Z. suturalis* adults were made and used to determine a distribution range (Fig. 1). At six locations, the ragweed leaf beetle was not found, although 10–20 ragweed plots (total, 1000–3000 m^2) per location were carefully inspected.

Statistical treatments

As could be expected, estimations of *Z. suturalis* population density made by counting and by sweeping closely correlated ($r = 0.78$, $n = 183$, Spearman rank correlation). Moreover, interrelations between data obtained by counting and by sweeping fit well ($r = 0.49$, Pearson correlation) with the linear regression $D_c = 0.14D_s$, where D_c is the population density estimated by counting, and D_s is that estimated by sweeping. Thus, the data obtained by two methods were combined with the formula $D_a = 1/2(D_c + 0.14D_s)$, where D_a is the averaged *Z. suturalis* population density (adults per square metre). This integral parameter correlated well both with the results of counting and those of sweeping ($r = 0.95$ and $r = 0.91$, correspondingly, Spearman rank correlation). In eight cases, when sweeping was not made, D_c was taken as D_a.

The ragweed population density was described not only by the height and percent cover but also by an integral characteristic, the ragweed abundance (the product of multiplication of the cover by the height). As the

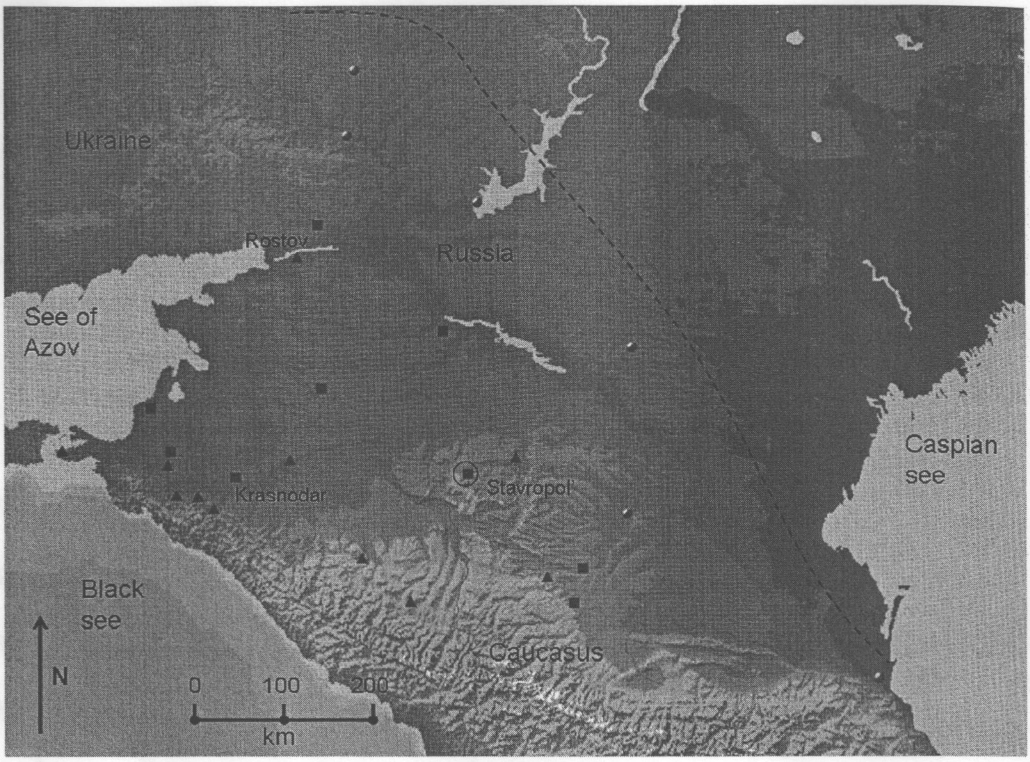

Figure 1. The geographical range of *Ambrosia artemisiifolia* and *Zygogramma suturalis* in Russia. Squares: Quantitatively studied locations; triangles: occasional records of *Z. suturalis* adults; circles: locations where *Z. suturalis* was not found; ring: the environs of the first release site, where the earlier studies (Reznik, 1993; Reznik *et al.*, 1994) were conducted; dash line: the approximate north-eastern boundary of the ragweed invasion.

distributions of *A. artemisiifolia* and *Z. suturalis* population densities were far from normal (Fig. 2), these data were transformed to decimal logarithms and then treated by analysis of variance (ANOVA), the Tukey test and linear regression analysis. Medians and quartiles of untransformed data were used as descriptive statistics. All calculations were made with SYSTAT 10.2.

Results

Wide-scale sampling shows that at present, the ragweed leaf beetle is widely distributed in Krasnodar territory, west of Stavropol' territory and south of Rostov province (Fig. 1). *Z. suturalis* population density was significantly ($F = 3.4$, $n = 191$, $p = 0.001$) different among nine quantitatively studied locations and positively correlated with the average ragweed abundance ($r = 0.91$, $n = 9$, $p < 0.001$). Two-way ANOVA of the transformed data on six locations where all main types of habitats (fields, field margins and ruderal sites) were inspected ($n = 164$) showed that the ragweed leaf beetle population density was more dependent on type of habitat ($F = 8.6$, $p < 0.001$) than on location ($F = 3.1$, $p = 0.012$). As for the ragweed, its height was slightly dependent on location ($F = 2.5$, $p = 0.03$) and strongly dependent on type of habitat ($F = 11.7$, $p < 0.001$), while percent cover was dependent only on type of habitat ($F = 57.3$, $p < 0.001$) but not on location ($F = 1.4$, $p = 0.23$). The Tukey test showed that ragweed height, percent cover and *Z. suturalis* population density in agricultural fields were significantly ($p < 0.001$) lower that that in field margins and in ruderal sites, while the difference between field margins and ruderal sites was not significant ($p > 0.3$). Thus, for further data analysis, field margins and ruderal sites were pooled and considered as 'stable' habitats, in contrast to crop rotation.

The average (hereafter, medians, quartiles and sample size are given) population density of the ragweed leaf beetle was very low, 0.001 (0–0.03) adults per square metre in agricultural fields subjected to crop rotation ($n = 40$) and 0.1 (0.04–0.27) adults per square metre in stable habitats ($n = 151$). However, in few of the studied plots, *Z. suturalis* population density ranges up to two to three adults per square metre (Fig. 2). Considering rather high level of ragweed infestation: percent cover 1% (0–2) and 40% (20–60%), height 10 (0–30) and 50 (30–80) cm in crop rotation and in stable habitats, correspondingly, it is not surprising that a detectable level of host plant damage (≥5%) was recorded only in one agricultural field (sunflower) and in few stable plots with relatively high density of the phytophage (Fig. 3).

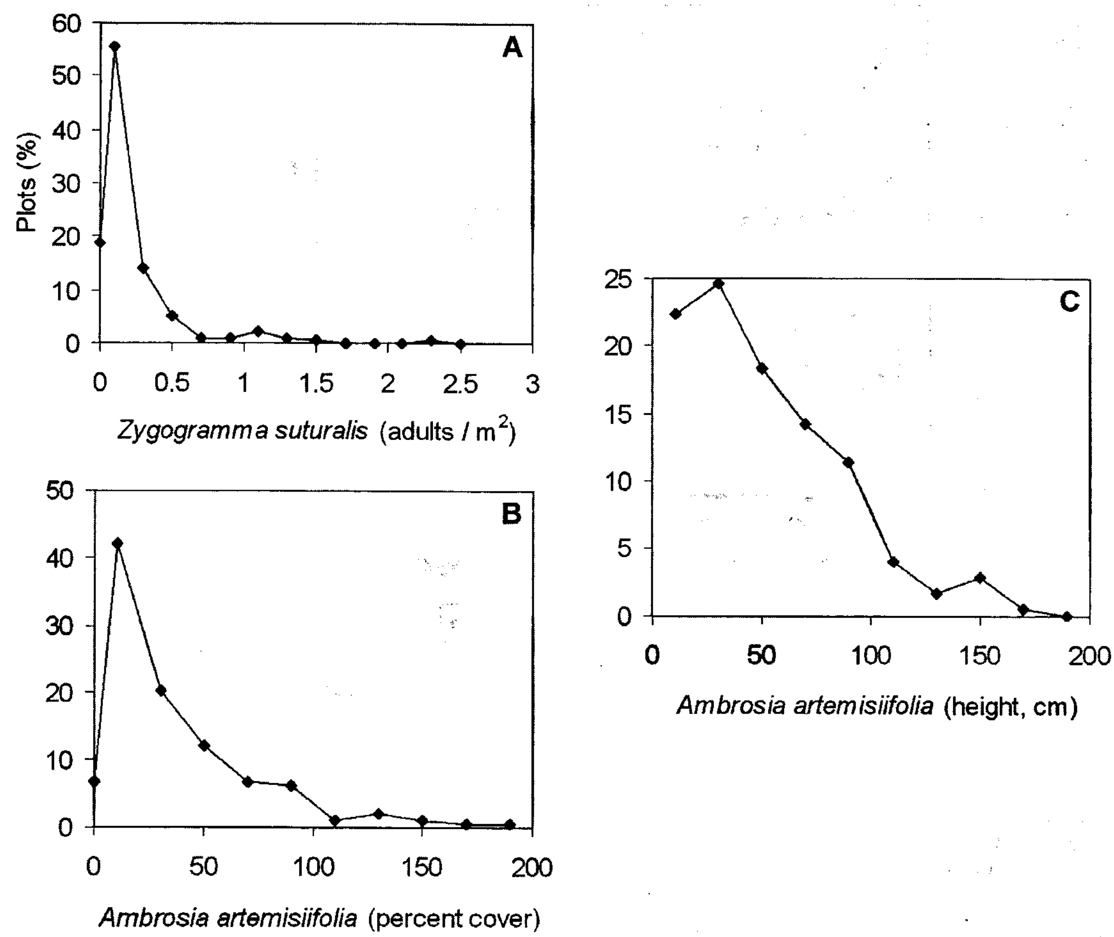

Figure 2. Distributions of the percent of studied plots according to the *Ambrosia artemisiifolia* and *Zygogramma suturalis* population densities which correspond to mean numbers of *Z. suturalis* adults per square metre (n = 191), ragweed percent cover (n = 191) and mean ragweed heights (n = 175).

It is noteworthy that, in spite of the drastic difference between medians, general linear model analysis showed that *Z. suturalis* population density significantly ($p < 0.001$) depended on the host plant abundance (cover multiplied by height) but not on the type of habitat ($p = 0.95$). Parameters of linear regression of log-transformed *Z. suturalis* population density on log-transformed ragweed abundance almost coincided: $Y = 0.62X - 3.2$ ($r = 0.60, n = 40, p < 0.001$) for crop rotations and $Y = 0.59X - 3.1$ ($r = 0.40, n = 151, p < 0.001$) for stable habitats (see Fig. 3 for untransformed data).

Discussion

First, our data suggest that *Z. suturalis* spreads practically over the whole area heavily infested by *A. artemisiifolia* in Russia (Ul'yanova, 2003), although it was not found in the less infested 'boundary zone'. Our observations suggest that in this zone, ragweed grows mostly in settlements and city environs, while in agricultural landscapes (including field margins), it is practically absent (unpublished data). It is well known (Maryushkina, 1986; Ul'yanova, 2003) that the northern limit of *A. artemisiifolia* geographical distribution in Russia is determined by the day length and temperature (ragweed is a typical 'short-day' plant) and the eastern limit by precipitation. Urban environments were shown to favor the ragweed establishment in the United States (Ziska *et al.*, 2006). Thus, it is possible that Russian settlements could also provide better conditions for the ragweed reproduction, i.e. more warm habitats in the northern boundary and more humid soil in the eastern boundary. Possibly, such a dispersed synanthropic distribution of ragweed in the boundary zone prevents or delays its colonization by the ragweed leaf beetle.

In the heavily infested zone, significant difference among studied plots and locations is most probably connected with uneven ragweed abundance but not with delayed colonization by the ragweed leaf beetle. An increase of the *Z. suturalis* population density with the *A. artemisiifolia* abundance was earlier recorded at smaller spatial scales (Reznik, 1993; Reznik *et al.*, 1994). As for the two components of the ragweed abundance, i.e.

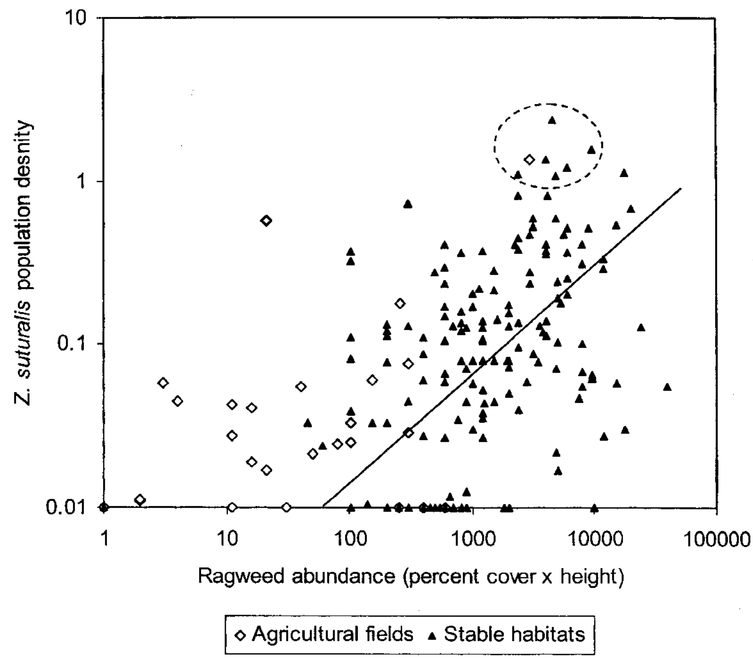

Figure 3. Relationship between *Ambrosia artemisiifolia* abundance (cover × height) and *Zygogramma suturalis* population density. *Each symbol* indicates one plot, an agricultural field subjected to crop rotation ($n = 40$) or more stable habitat: field margin, roadside, ruderal site, etc. ($n = 151$). *Regression line* ($Y = 0.61X - 3.1$, $r = 0.62$, $n = 191$, $p < 0.001$) is based on the log-transformed pooled data. *Dashed ellipse* indicates plots with a detectable rate of the ragweed damage (≥5% of the total leaf surface).

percent cover and average height, it is interesting that relatively stable habitats mostly differed from crop rotations not in ragweed percent cover but in its height. This could be explained by the fact that mowed ragweed can regrow quickly, producing many leaves on short stems. Hence, at the same percent cover in stable habitats, ragweed is much higher.

Note that *Z. suturalis* population densities recorded in 2005 to 2006 were lower than those observed during our previous investigations (Reznik, 1993; Reznik *et al.*, 1994; Reznik, 1996). As for the data obtained by other authors, the comparison is hampered by the fact that, very often, not average values but upper limits were published. Maximal *Z. suturalis* population density recorded in Stavropol' and Krasnodar territories at the end of the 1990s was six and 50–70 adults per square metre, respectively (Polovinkina and Yaroshenko, 1999; Os'kin, 2002), which is similar to our data obtained in 1988–1989 (Reznik *et al.*, 1994) but much higher than the results of the present. One of the recent papers (Esipenko and Belikova, 2004) also pointed out a significant decrease in the *Z. suturalis* population density. This assertion is indirectly supported by the fact that in several regions of Krasnodar territory, where in 1993 the ragweed leaf beetle population density ranged up to 400 adults/m^2 (Ugryumov *et al.*, 1994), in 2003, only 166 adults were collected for phenetic analysis (Esipenko and Savva, 2004). It is not clear if this decline in population density is connected with recent climatic changes, with increasing impact of natural enemies, or with some other factors (Esipenko and Belikova, 2004).

Thus, our results suggest that, by now, the ragweed leaf beetle had spread throughout most of its potential area, and further expansion is unlikely. The observed spatial variation of *Z. suturalis* population density seems to be mostly determined by the host plant abundance. The last is strongly dependent on the stability of the habitat, being much lower in crop rotation fields. In overwhelming majority of inspected populations, the impact on the targeted weed is negligible. However, having regard to the spectacular success achieved in the permanent experimental plot from 1983 to 1985 (Kovalev, 1988), it is still possible that stable protected field nurseries could be a promising method of *Z. suturalis* propagation for biological control of ragweed in surrounding areas.

As already highlighted by the biological invasion theory, we conclude that, in spite of certain prerequisites for invasion (abundant food resources, absence of competitors, specific parasitoids and predators), very strong population explosion recorded during first years after introduction finally resulted in wide geographic distribution but low mean population density and negligible ecological role of an alien insect species.

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