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Classical biocontrol of weeds in crop rotation: a story of failure and prospects for success

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Abstract. It is well known that most successes with classical biocontrol of weeds have been achieved on weeds of uncultivated land. The prospects for classical biocontrol of weeds in crop-rotation systems are discussed using the case of *Zygogramma suturalis* on ragweed as an example. The chrysomelid, *Z. suturalis*, was introduced into Russia in 1978 to control the common ragweed, *Ambrosia artemisiifolia*. *Zygogramma suturalis* successfully established and from 1983-1985 it suppressed ragweed at the release site and in several neighbouring fields. However, an estimate of *Z. suturalis* densities from 1988-1994, over 25000 ha around the first release site, showed very low mean densities, about five beetles kg^{-1} of ragweed (0.2 beetles m^{-2}). Apart from a few small patches where insects were numerous, the ragweed leaf-beetle was not sufficiently damaging to reduce the density of the weed. The results of this introduction can be considered as a moderate success. Theoretically, organisms with excellent search- and dispersal-abilities (some insects) or those showing persistence (some fungi) can be used for classical weed biocontrol in unstable, disturbed habitats.

Introduction

Common ragweed, *Ambrosia artemisiifolia* L. (Asteraceae) is one of the most noxious weeds in the former Soviet Union. In 1978, in an effort to control this weed, the ragweed leaf-beetle, *Zygogramma suturalis* F. (Coleoptera: Chrysomelidae) was introduced from the United States of America and Canada into the Stavropol region (Russia) by Dr O.V. Kovalev (Zoological Institute, St. Petersburg). It was a pioneering project aimed at biocontrol of an annual weed in a crop-rotation system.

Within about five years of its release, from 1983-1985, *Z. suturalis* suppressed ragweed at the release site and in some of the neighbouring fields, where the leaf-beetle population density was sufficiently high (Kovalev *et al.* 1983). In some fields, a 'population wave' was recorded, leaving behind an area in which the weed had been completely devastated (Kovalev and Vechernin 1986). This gave rise to several optimistic publications (Kovalev 1989; Harris 1991). Further investigations have showed that the ragweed leaf-beetle was not able to control ragweed (Reznik 1993; Reznik *et al.* 1994). Recently, *Z. suturalis* was introduced against *A. artemisiifolia* in Yugoslavia, China and Australia (Igrc 1987; Wan and Wang 1990; Julien 1992).

Monitoring and reporting of unsuccessful results as well as of successful ones is important in improving the theory of agent selection in weed biocontrol (Schroeder and Goeden 1986). The present paper aims at identifying the factors that influence the effectiveness of biocontrol agents against annual weeds in cropping systems, using the ragweed leaf-beetle as an example. The results of the long-standing evaluation of *A. artemisiifolia* and *Z. suturalis* population densities are summarized, and both original and previously-published data and interpretations are included.

Materials and methods

All the fields within a radius of 10-12 km of the first *Z. suturalis* release site (approximately 250 km^2) were sampled during 1988-1989 and certain of these fields, selected randomly, were sampled from 1991-1994. In all, 1532 fields were surveyed. The methods of field-sampling have been described earlier (Reznik 1993; Reznik *et al.* 1994). Taking a finer spatial-scale (within a field), 0.1 m^2 plots were sampled. In each plot *Z. suturalis* population densities, the wet-weight of the ragweed and the mean degree of ragweed damage were estimated. Over the broad spatial-scale, a visual rating was used. Each field was described according to the mean insect- and ragweed-densities over the whole field (mean densities) and by their densities in the ragweed patches with the highest *Z. suturalis* density for the field studied (patch densities).

Results and discussion

At present, the ragweed leaf-beetle is widespread over the distributional range of ragweed in Russia and the Ukraine (south of 50°N). However, from 1988-1994 the estimated mean densities of *Z. suturalis* over 25000 ha, around the first release site, were low (Fig. 1a). *Zygogramma suturalis* was not recorded in many of the ragweed-infested fields. A mean relative density (per ragweed-weight-unit) of more than 5 beetles/kg was recorded in 14% of the fields (see also Fig. 2). Only in 0.5% of the fields was the relative density more than 50 beetles/kg, which is sufficient for there to be detectable damage, but not for significant destruction of the ragweed. This explains why, from 1988-1994, significant damage to ragweed has only been recorded on several small (50-200 m²) patches where the beetles reached high densities (Fig. 1b). Usually, these patches were located at field margins where the beetles could avoid harmful agricultural practices such as ploughing, harvesting and pesticide treatments.

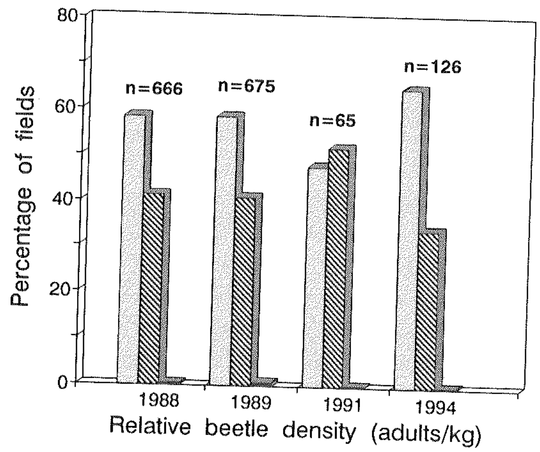

Fig. 2. Frequency distribution of fields with different *Z. suturalis* mean relative densities (per ragweed-weight) from 1988-1994. Light stipple - mean relative density = 0; diagonal hatching - mean relative density <10; and black - mean relative density >10.

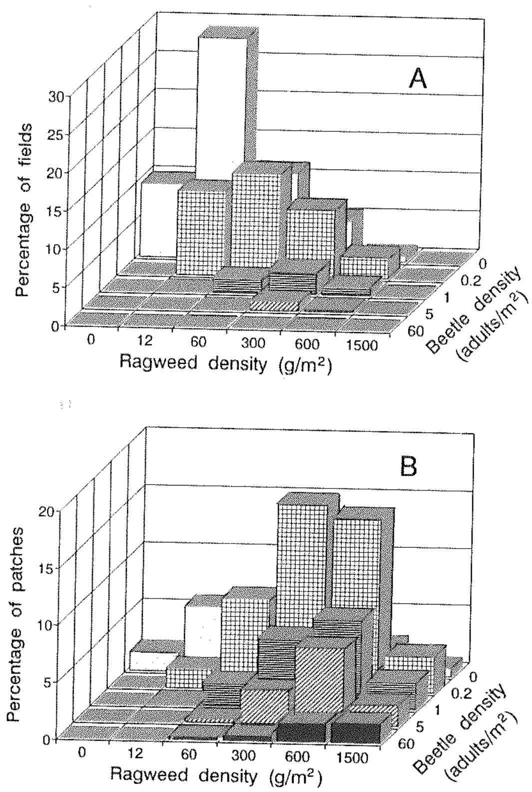

Fig. 1. The relationships between *A. artemisiifolia* and *Z. suturalis* population densities. A - mean insect and plant densities in the whole field (mean densities). B - mean insect and plant densities in the ragweed patches with the highest *Z. suturalis* density for the field studied (patch densities).

Ovipositing females of *Z. suturalis* prefer large ragweed plants and plant patches with high ragweed-density (Reznik 1993). Sometimes the beetles aggregated in such patches after most of the ragweed had been destroyed through the cultivation of crops in the area. However, a correlation analysis showed that these patches had no effect on the mean beetle-density in the following season. Between-fields analyses suggested that the absolute density of *Z. suturalis* was determined by current ragweed densities (Fig. 1a) and was only slightly dependent on the previous year's beetle densities (see also Reznik *et al.* 1994).

A 'population wave' turned out to be an extremely rare event. Laboratory experiments and field observations showed that *Z. suturalis* females from heavily-damaged ragweed plants produced fewer eggs and were more likely to enter diapause than those on healthy plants. Ovipositing females of *Z. suturalis* prefer to feed on undamaged plants. However, during a short period from the emergence of young adults of the first generation, to the beginning of their oviposition period, the majority of females display little or no response to the level of ragweed damage (Vinogradova and Bogdanova 1989; Reznik 1989, 1991). Only in these circumstances, and where other conditions are favourable, may overpopulation (more than 500-1000 beetles per kg of ragweed) result in a 'population wave'.

As expected, ragweed densities were dependent on the associated agricultural crop. All the crops were categorized according to mean ragweed-densities, and the mean relative densities of *Z. suturalis* were calculated separately for each crop-group. The mean relative-beetle-density was independent of ragweed density, almost irrespective of the agricultural crop. However, perennial fodder legumes showed much higher *Z. suturalis* densities than annual crops (Fig. 3). Most success with classical biological control has been achieved on weeds of permanent habitats. Julien (1989) reasoned that annual weeds that are subject to cultivation are not readily amenable to classical biological control because the probability of establishment of natural enemies decreases as the degree of habitat-stability decreases (Hall and Ehler 1979; Harris 1991). Perennial legumes could be considered as 'intermediate habitats', while annual crops are 'unstable habitats' (Hall and Ehler 1979).

We conclude that the results of the ragweed leaf-beetle introduction into Russia can be considered as a 'moderate success', but not as a 'complete success' (Harris 1991). Despite a few small patches with high densities of the chrysomelid, the ragweed leaf-beetle was not sufficiently damaging to reduce the density of the weed to acceptable levels. However, in stable, undisturbed locations, *Z. suturalis* can cause extensive damage to ragweed plants over a two- or three-year

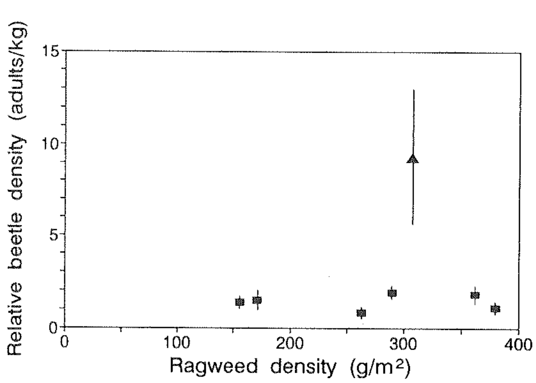

Fig. 3. Mean relative densities (per ragweed-weight) for *Z. suturalis* in annual crops and a perennial crop (fodder legumes). Means ±SE are shown. Rectangles - annual crops; Triangle - perennial crop.

period, depending on the density of the initial colonization.

If a potential agent for classical biological control is to be successful in crop rotation, it should exhibit the properties of the most injurious pest species. Generally speaking, two types of organisms are tolerant of crop rotation, and accordingly, two types of weed biocontrol agents may successfully be used in unstable habitats. By analogy with insect pest control (Murdoch *et al.* 1985), the first type might be termed 'search-and-destroy' and the second as using a 'lying-in-wait' strategy. Obviously, both types of agents should be more or less tolerant of disturbances such as ploughing, harvesting and chemical treatments. Such tolerance is quite common both in insects and in fungi.

As the phrase implies, a biocontrol agent of the 'search-and-destroy' type has a high rate of dispersal and is adapted to find and to suppress the weed. *Leptinotarsa decemlineata* Say. is an example of a pest of this type. The capacity of the Colorado potato beetle to survive and to suppress its host plant in spite of crop rotation is self-evident. *Leptinotarsa decemlineata* has excellent long-distance chemoreception and can reach outlying potato fields by flight (Hare 1990). Even so, a distance of 0.4 km between rotated locations was sufficient to reduce early-season defoliation by *L. decemlineata* by 50% (Weisz *et al.* 1994). In *Z. suturalis*, long-distance chemoreception is weak and the adults are reluctant to fly. Under natural conditions, beetles usually crawl over the plant and soil surface (Reznik and Kovalev 1989). A computer simulation of the population dynamics of *Z. suturalis* and of *A. artemisiifolia* (in collaboration with O.V. Kovalev and A.L. Lobanov unpublished) showed that search and dispersal ability, rather than voracity or fecundity, limits the biocontrol efficiency of this chrysomelid.

A biocontrol agent of the second type, i.e. 'lying-in-wait', is more-or-less present continuously in areas subject to the weed infestation. An agent of this type is capable of suppressing the target weed and then of resisting starvation over a long period of time. In contrast to insect parasitoids and predators, weed biocontrol agents cannot survive adverse periods on secondary hosts, because there is a requirement that they are host-specific. The persistence of the spores of certain phytopathogenic fungi is sufficiently high for them to survive through periods of adverse conditions.

In insect-pest biocontrol, the host-finding ability of natural enemies is considered an important component of their effectiveness in diversified agroecosystems

(Vet and Dicke 1992; Corbett and Plant 1993). This feature was not included in the scoring system for prediction of the effectiveness of agents for the biological control of weeds (Harris 1973). However, the single success of classical biocontrol of weeds in cultivated annual crops cited in the review papers by Harris (1991, 1993) was explained by the high dispersal-ability of a rust disease. Even in stable conditions, strong, directed flight and excellent abilities to locate the host are regarded as key features in a successful weed biocontrol agent (Dennill 1990). Supposedly, both searching ability and persistence should be taken into account in future studies of the biological control of weeds in unstable, disturbed habitats.

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