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On Assessment of the Large-Scale Effect of Introduction of the Ragweed Leaf Beetle *Zygogramma suturalis* F. (Coleoptera, Chrysomelidae) on the Phytocenoses of South Russia

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Abstract—Evaluation of the efficiency of large-scale projects of phytophage introduction for weed control is of importance for both the theory and practice of biological control. Introduction of the ragweed leaf beetle *Zygogramma suturalis* F. into the USSR in the 1960–80s is an example of such a project. The main theoretical result of this project was the discovery of the phenomenon of the solitary population wave (SPW), which is a necessary condition for successful biological control of the invasive weed. Recent investigations confirm the long-term efficiency of acclimation of the common ragweed phytophages in the South of Russia. The disappearance of a huge phytomass of the common ragweed in the fields, an abrupt drop in the seed density in the soil, reduction of the infestation areas, and absence of large and dense weed patches in satellite images testify to the fact that the goal of phyto-phage introduction, i.e., suppression of the common ragweed in agrophytocenoses, has been met. The tasks of the next phase of ragweed suppression are discussed in view of the role of the common ragweed as a synanthropic allergic agent and a ruderal plant growing in anthropogenically transformed territories.

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Globalization has aggravated the problem of anthropogenic transformation and degradation of the biosphere. The intensity of unintentional transfer of plant and animal species between continents has increased manifold. Given suitable conditions, invaders get effectively naturalized in new habitats, reducing the species diversity of the natural ecosystems and exhausting their resources. In particular, some adventive plants can occupy the dominant position in phytocenoses by suppressing and replacing local vegetation and form extended infestation foci which for years block the succession process (Kovalev, 2004b; Mirkin and Naumova, 2012). This negative process is furthered by anthropogenic disturbance of ecosystems which weakens the autochthonous species and raise the competitive ability of invaders which have no specific enemies in secondary ranges (Elton, 1958; Kovalev, 1989a). Therefore, the biological methods of suppressing invasive weeds are based on using highly specialized phytophages (Huffaker, 1957, 1978; Kovalev, 1971).

Although the theory of biological weed control has been developing over 150 years, it still cannot ensure predictable results of selecting the control agents and efficiency of their introduction (Myers, 1985; Briese, 2000; Myers and Bazel, 2003; van Klinken and Raghu, 2006; Müller-Schärer and Schäffner, 2008). Analysis of the data from the *World Catalogue of Agents and Their Target Weeds* (Julien and Griffith, 1998) carried out by McFadyen (2000) shows that only some campaigns of phytophage introduction have turned out to be effective in the end. Successful introduction of phytophagous insects from the native range of adventive plants allows agricultural producers to save millions of dollars spent annually on suppression of weed foci by chemical or technical methods (Kovalev, 1989a; McFadyen, 2000). The question is the possibility of recovery of considerable capital investments needed for the complete cycle of scientific development and practical implementation of the biological control method for a new weed species. McFadyen (2000) assessed annual expenditure at 200 to 500 thousand dollars during 5–15 years, 3–8 million dollars in total, pointing out that underfunding was the frequent cause of failure of the biological control method. Further use of the previously selected agents, which have already proved their efficiency and safety in practice, may turn out still more economic. For example, every dollar spent on introduction of the South American salvinia weevil *Cyrtobagous salviniae* Calder et Sands (Coleoptera: Curculionoidea, Erirhinidae) into Sri-Lanka brought a 1675 dollar profit (Doeleman, 1989), since this phytophage had been already studied and found to be highly effective against *Salvinia molesta* D.S. Mitchel in Australia, New Guinea, and other countries (Room et al., 1981; Room and Thomas, 1985; Room, 1990; Julien and Griffith, 1998). Thus, the results obtained during the complete cycle of development and implementation of biological methods of invasive weed control are of special scientific significance and practical value, which goes far beyond the particular goal of suppressing a certain invasive species in some region.

Development and introduction of new methods of biological suppression of adventive weeds is available only to developed countries, large companies, and scientific research centers. One of such large-scale projects in Russia is the work on selection, introduction, and acclimation of North American phytophages of the common ragweed *Ambrosia artemisiifolia* L. (Asteraceae), which was carried out in the Soviet Union in the 1960–1980s. Within the framework of this project, data were collected on the biology of 527 species from 69 families and 9 orders of insects and mites living on plants of the subtribe Ambrosiinae in North America, including narrow oligophages: fruit flies, leaf beetles, the olive-shaded bird-dropping moth, gall midges, and weevils (Kovalev, 1989a). Acclimation of only one of the most effective agents, the ragweed leaf beetle *Zygogramma suturalis* F. (Coleoptera, Chrysomelidae), was carried out in those years in 16 provinces of the former USSR, from Ukraine to the Far East, whereas the most intensive work was performed in the South of Russia, mainly in Rostov Province and Stavropol and Krasnodar Territories (Kovalev, 1971, 1989a; Kovalev and Medvedev, 1983; Kovalev and Belokobylskij, 1989).

The Significance of the Experience of the Ragweed Leaf Beetle Introduction for the Theory and Practice of the Biological Control Method

Retrospective analysis of the stages of the ragweed beetle introduction, as compared with the results of other large-scale weed biocontrol projects, makes it possible to draw a lesson which would help us understand the factors of biomethod efficiency, and also reveal the characteristic problems which objectively impede both realization and assessment of the long-term efficiency of large-scale biocontrol projects.

One of such problems is the absence of agreement among specialists on the number of species of phytophagous insects needed for suppressing the weed. The concept of the so-called "cumulative effect" of a multitude of control agents (Huffaker, 1978; Harris, 1981) does not find convincing support either in practice or in theoretical studies (Myers, 1985; Krug and Richardson, 2014). On the contrary, data show that the maximal effect may be achieved by using only one of the introduced phytophages (Myers, 1985; McFadyen, 2000), which Myers and Coombs (1999) called the "silver bullet." The method efficiency is ensured not so much by the biological characteristics of the introduced phytophage as by the presence of conditions for the formation of its solitary population waves (SPW), a phenomenon which was discovered during introduction of the ragweed leaf beetle from Canada to the South of Russia (Kovalev and Vechernin, 1986, 1989; Kovalev, 1989c) and may be observed only in the secondary range of the invasive species (Kovalev, 2004b; Kovalev and Tyutyunov, 2014).

As well as in other cases of successful use of phytophages, the formation of the ragweed leaf beetle SPW was preceded by a fast growth of its numbers. Mere 1500 beetles released in 1978 in the environs of Stavropol (Kovalev, 1989a) gave rise to a population which grew manifold in the next generations (Cherkashin, 1985; Kovalev and Vechernin, 1986). As the result of progress of the SPWs which formed in the initial release area, the leaf beetle considerably extended its range during 10 years after introduction and colonized the whole Black Sea basin. Destruction of the dense ragweed foci by the naturalized phytophage increased the crop yields, drastically reduced the density of ragweed seeds in the soil, and restored the natural succession in phytocenoses (Kovalev and Vechernin, 1989, Kovalev, 2004b; Kovalev et al., 2013).

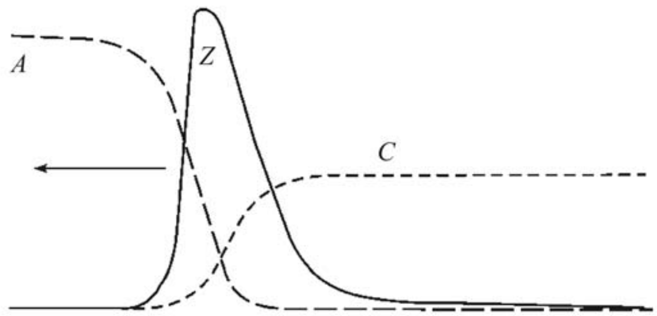

Fig. 1. The passing of the phytophage SPW (*Z*) suppressing the dominant weed (*A*), and the subsequent fixation of the SPW effect by the cultivated plant (*C*). The arrow shows the direction of the wave front movement.

Similar to combustion autowaves, SPWs of the phytophage introduced from the native range of the weed create conditions for inextinguishable, explosive rise in the insect abundance due to spatial expansion. It is interesting that although locally such a population outbreak of the phytophage is based on the classical "bottom-up control" that is typical of most natural ecosystems (White, 1993, 2013), the expansion of the SPW of the control agent creates the conditions for the systemic "top-down control" of the trophic system, which ensures suppression of the extended and dense weed foci (Kovalev, 1989c; Tyutyunov et al., 2013; Kovalev and Tyutyunov, 2014).

Understanding of the fact that SPW formation is the necessary condition of successful use of the phytophages may considerably raise efficiency and predictability of the biological control method: the wave formation should be considered as the necessary prerequisite at all the stages of the project, from agent selection to its release (Kovalev and Tyutyunov, 2014). At the stage of the phytophage selection, this concept allows one to narrow down the list of potential control agents to phylogenetically young "juvenile taxa" which can form SPWs during invasion into secondary ranges (Kovalev, 1998; Kovalev, 2004a, 2007). The taxonomic position of such promising control agents was discussed in the previous publication (Kovalev and Tyutyunov, 2014). On the contrary, at the stage of agent release, of considerable significance is selection of large and dense weed foci with high phytomass which would ensure the initial build-up of the phytophage abundance at the initial phase of the SPW formation. The importance of these preliminary measures was confirmed by both field experience (Cherkashin, 1985; Kovalev and Vechernin, 1986, 1989) and mathematical simulations (Kovalev and Vechernin, 1986, 1989; Tyutyunov et al., 2013).

While supplementing the field studies, the mathematical models of the spatio-temporal dynamics of the studied trophic systems give an idealized description of the interactions between the populations of the phytophagous insect, the weed plant, and the cultivar competing with it (Kovalev and Vechernin, 1986, 1989; Tyutyunov and Titova, 2013; Tyutyunov et al., 2013). Such models can explain both the regularities of microevolutionary changes in the phytophage population (Kovalev, 1989b; Tyutyunov et al., 2007, 2013; Edmonds et al., 2008; Hallatschek and Nelson, 2008; Lehe et al., 2012) and the mechanism of SPW efficiency: the local result of suppression of dense weed biomass in the passing of the SPW is reinforced by the competitors of the common ragweed which remain suppressed in the absence of the leaf beetle (Fig. 1). The results of field research and observations, and also computing experiments with mathematical models reveal the systemic effect of the biological weed control method, which is intensified manifold due to synergistic interaction of phytophage population waves and competitive replacement of the weed by the local plant species (Kovalev and Onosovskaya, 1989; Ipatov et al., 1989; Kovalev et al., 1989; Matishov et al., 2011). At the population level, the wave itself is the result of self-organization of a great number of insects randomly moving in search of food (Kareiva and Odell, 1987; Tyutyunov et al., 2009, 2010); therefore, high productivity of the host plant triggering the outbreak of the phytophagous insect is of crucial significance for its development (Tyutyunov et al., 2013).

*Long-term Efficiency of the Common Ragweed Suppression in the Agrocenoses of the South of Rus*sia

The concept of the stepwise systemic effect of the phytophage SPW on phytocenoses (a rapid increase in the insect abundance after introduction into the secondary range of its host plant—the formation and progress of SPWs practically wiping out the weed—restoration of the natural succession in the treated territories) was proposed and fully tested as early as the 1980s (Kovalev and Vechernin, 1986, 1989; Kovalev, 1989c), but was not completely understood at that time. To a considerable degree, this could be accounted for by one more common problem of large-scale projects of phytophagous agent introduction, namely, the fact that even with sufficient financing, the greatest part of the funds falls on the initial stages of introduction, whereas assessment of efficiency, especially long-term one, attracts much less attention (McEvoy and Coombs, 1999). During introduction of the ragweed leaf beetle into the South of Russia, economic recession preceding the disintegration of the Soviet Union was an additional negative factor which finally led to termination of large-scale research at the closing stage of the project. As a result, after discovery and description of the very phenomenon of the ragweed leaf beetle SPW and assessment of its effects on the phytocenoses and crop rotation systems in the South of Russia, entomologists did not continue field and theoretical research of large-scale changes caused by the SPW. The economic effects associated with elimination of the huge weed phytomass in crops, which reached 100 t/ha before the leaf beetle introduction (Cherkashin, 1985; Kovalev, 1989a), were not assessed, either. Analysis of these data started only recently, after evidence was obtained of the long-term effect of the leaf beetle acclimation, in particular, a steep reduction of the ragweed infestation level in the South of Russia as compared with the 1970s (Kovalev et al., 2013; Kovalev and Tyutyunov, 2014). In particular, the field studies of 2012–2013 included assessment of the weed seedling density, soil sampling, and analysis of the ragweed seed pool in the agrocenoses of the North Caucasus (Rostov Province, Krasnodar and Stavropol Territories, the Republic of Adygeya). The results of processing soil samples taken in 2012 in the agrophytocenoses of Rostov Province and Adygeya were published earlier (Kovalev et al., 2013). The test plot results of 2013 (see Table 1) from Shpakovskii, Izobilnyi, and Novoaleksandrovskii Districts of Stavropol Territory and from Gulkevichskii, Tikhoretskii, Tbilisskii, Kavkazskii, Pavlovskii, and Kushchevskii districts of Krasnodar Territory are presented in Table 2. Most of the processed samples revealed a "weak" or "very weak" level of soil infestation on the five-point evaluation scale (Fisyunov, 1974). No samples corresponding to "very strong" infestation were discovered (Matishov et al., 2012; Kovalev et al., 2013), even though such levels were typically observed before the introduction of ragweed phytophages into the South of Russia (Kovalev, 1989a; Kovalev and Vechernin, 1986, 1989).

Thus, field research revealed not only high efficiency of introduction of ragweed phytophages performed in 1978–1990 but also preservation of the effect during 30 years. Why was not objective assessment of its efficiency given earlier?

Besides the problems mentioned before, such as irregular distribution of funds and insufficient financing at the final stages of phytophage introduction, there are also other reasons impeding timely assessment of the long-term efficiency of such projects. In particular, McFadyen (2000) noted the gradual nature of transformation of vast phytocenoses due to phytophage invasion, the "short memory" of the witnesses, lack of archive materials, in particular photographs recording the state of ecosystems before releasing the control agents, and also the fact that not all the participants of the initial stages of research retain interest and the possibility to follow up the changes in vast territories during the next two decades. As a result, the new generations of researchers cannot always assess objectively the initial state of ecosystem disturbance which required the use of the biological method.

Therefore, in assessing the efficiency of the common ragweed suppression one should use such objective criteria as the density of ragweed seeds in the soil and the number of ragweed plants per 1 m^2. At present, these values are one or two orders of magnitude lower than those recorded in the 1970s (Kovalev and Vechernin, 1986; 1989; Kovalev et al., 2013). Of no less value are old photographs which give an idea of the degree of infestation in the years previous to the leaf beetle dispersal. For example, Figs. 2 and 3 show complete infestation of vegetable crop fields with the common ragweed, which was typical of that period and provided ideal conditions for build-up of the leaf beetle abundance and formation of its population waves after introduction. Now, when the common ragweed has lost its position of the dominant weed in agrophytocenoses, such landscape photographs convey the idea of "very strong" infestation (according to Fisyunov, 1974), which would not yield to either mechanical or chemical methods (Kovalev, 1989a).

It is interesting that very similar SPWs of several species of the genus *Chrysolina* Motsch. (Coleoptera,

Table 1. Coordinates and characteristics of survey plots along the expedition route in 2013, from Pelagiada (Stavropol Territory) to Tikhoretsk (Krasnodar Territory)

Plot	N	E	Cultivar
1	45°9′14.4″	41°58′23.4″	pea
2	45°13′27.4″	42°3′49.3″	peanut
3	no data	no data	wheat
4	45°10′0.6″	41°58′20.5″	pea
5	45°14′43.6″	41°50′0.05″	corn
6	no data	no data	wheat
7	45°26′22.6″	41°20′41.3″	corn
8	45°23′21.4″	40°37′44.3″	garden
9	45°23′31.9″	40°40′20.4″	sunflower
10	45°21′46.8″	40°15′54.3″	alfalfa
11	45°21′46.8″	40°15′54.3″	along the road
12	45°22′45.7″	40°19′57″	corn
13	45°23′26.5″	40°38′24.6″	fallow
14	45°24′54.1″	40°42′9.4″	fallow
15	45°22′52.2″	40°43′6.7″	sunflower
16	45°50′59″	40°9′57.3″	corn
17	45°51′52.4″	40°16′57″	corn
18	45°52′39.6″	40°24′48″	corn
19	45°48′29.5″	40°6′14.1″	cabbage
20	45°45′50.8″	40°9′58.1″	sunflower
21	46°5′0″	39°54′38.3″	sunflower

Table 2. The density of common ragweed seeds in fields of different cultivars

Cultivars	Survey plots	Number of survey plots	Number of common ragweed seeds in the upper 0–20 cm of soil, per 1 m^2
Pea	1, 4	2	42–54
Peanut	2	1	24
Corn	5, 7, 12, 16, 17, 18	6	85–110
Wheat	3, 6	2	47
Alfalfa	10	1	23
Cabbage	19	1	76
Sunflower	9, 15, 20, 21	4	80–135
Garden	8	1	62
Fallow	13, 14	2	68–127
Roadside	11	1	156

Chrysomelidae) accompanied the destruction of the dense growth of the Eurasian St. John's wort *Hypericum perforatum* L. (Clusiaceae) in the vast territories of North America in the 1950s (Huffaker, 1967; Julien and Griffiths, 1998). As the result of biological control application, St. John's wort did not disappear completely on the American continent but simply became a "regular" weed which did not pose more serious problems to agriculture as compared with other weeds. Nor did the acclimated leaf beetles disappear, though the density of their populations is much lower now as compared to the level observed in the period of

Fig. 2. A potato field infested with the common ragweed, Stavropol Territory, 1980 (photo by O.V. Kovalev).

Fig. 3. A marrow squash field infested with the common ragweed, Stavropol Territory, 1980 (photo by O.V. Kovalev).

SPW formation and passing. A similar situation was observed in the South of Russia after application of biological control measures against the common ragweed. These two cases of successful use of the biological method have one important difference: the common ragweed is not only an agricultural weed but also a very strong incitant of allergy. In our opinion, this circumstance was also to a considerable degree conducive to the underestimation of the effect of the ragweed beetle introduction, since, even though the common ragweed was reduced to the level acceptable to agriculture by the end of the 1980s, this did not solve the problem of allergenic pollinosis. However, it should be borne in mind that it was weed control in agrocenoses that was the main task of phytophage introduction in the 1970–1980s (Kovalev, 1989a); therefore, it is the efficiency of weed control which should be assessed.

Since the initial purpose of the leaf beetle introduction was reducing the ragweed seed pool (Kovalev, 1989a), assessment of the method efficiency should be based on such an objective criterion as the density of ragweed seeds in the soil (Fisyunov, 1974; Cherkashin, 1985; Kovalev and Vechernin, 1986, 1989; Kovalev et al., 2013). Ignoring of this criterion and

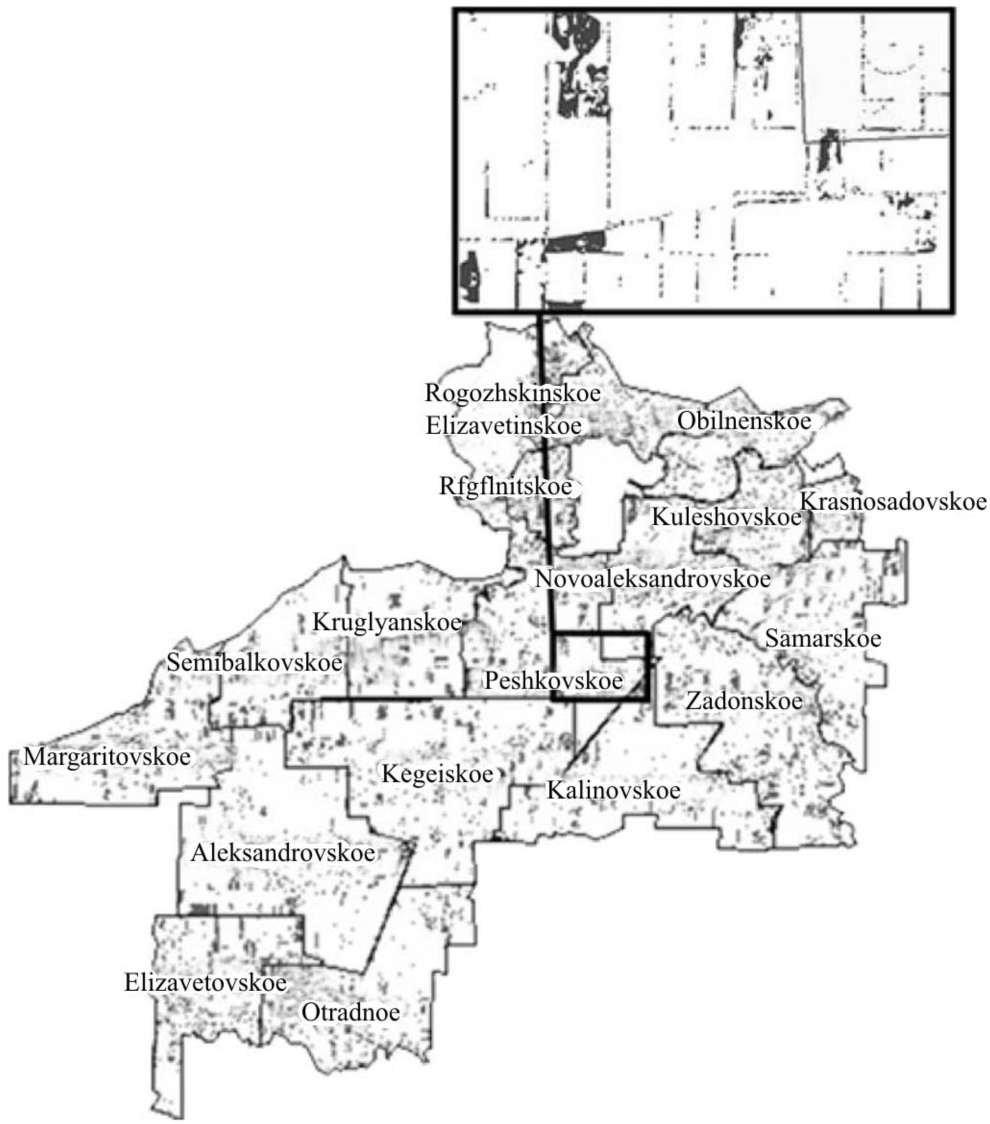

Fig. 4. Infestation of settlements with the common ragweed in Azov District, Rostov Province, in 2009–2013. The infestation spots mostly occur at the field edges and roadsides, as can be seen in the magnified photograph of Peshkovskoe.

substitution of it by other parameters, in particular, by the size of the ragweed range or the leaf beetle population density 20 years after suppression of the weed foci (Reznik, 2009) would result in incorrect evaluation of efficiency of the ragweed leaf beetle introduction.

The Use of Satellite Images for Assessment of Efficiency of the Ragweed Leaf Beetle Introduction

There are also technical complexities of the analysis of large-scale changes caused by introduction of phytophages of invasive weeds into phytocenoses. Research methods based on assessment of the seed density in the soil or the seedling density of the weed, analysis of the dynamics of its projective cover or phytomass, and the area of infested phytocenoses are extremely labor-consuming. Besides, it is quite impossible to reconstruct the full picture of spatio-temporal ecosystem dynamics based on isolated and irregular local observations (Embleton and Petrovskaya, 2014). The field trips of researchers and subsequent processing of soil samples are expensive and time-consuming. However, even if many local samples are available and regular route surveys are performed it is fairly difficult to have a comprehensive idea of the degree of infestation of phytocenoses with the ragweed. As a rule, data on the size and location of foci and the infestation level collected in this way are not only insufficiently detailed but also may turn out to be subjectively overestimated or incomplete. The absence of detailed spa-

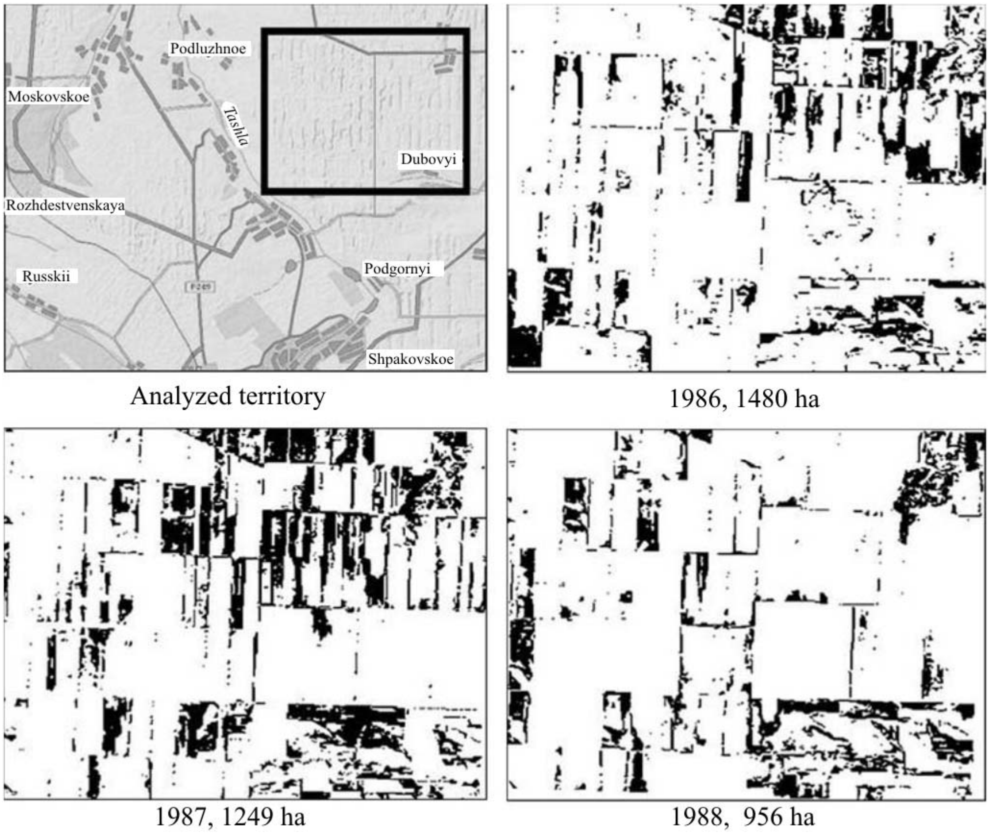

Fig. 5. Infestation of fields with the common ragweed in Stavropol Territory in the late 1980s.

tial picture impedes assessment of the efficiency of weed control measures.

Satellite monitoring data hold much promise for solving this task. The modern Earth remote sensing (ERS) methods, based on the analysis of satellite data, supplement the traditional methods of studying phytosenoses and allow one to observe vast territories almost instantaneously. The unique possibilities provided by satellite imaging in different parts of the EM spectrum include multispectral photography, thermal infrared survey, and all-weather photography of the studied territories and objects.

The use of ERS data for revealing ragweed-infested territories was for the first time suggested by Asselin and Mopin (1998). This approach includes creating databases of the spectral characteristics of different plants and rocks (Maupin and Boivin, 2001) and using them to identify different types of vegetation in satellite photographs of medium and high resolution. Development of methods of detecting the ragweed foci by means of ERS data is a very urgent task (Auda et al., 2011; Csornai et al., 2011). Alongside with complicated algorithms of processing high-resolution hyperspectral satellite images and search for the most informative channels which would permit identification of particular weed species (Kozoderov et al., 2012; Bondur, 2014), of high efficiency are express methods of integral infestation assessment based on the normalized difference vegetation index (NDVI) (Kriegler et al., 1969; Rouse et al., 1973) of vast territories photographed at medium resolution (Arkhipova et al., 2014).

We used a 4-channel Skye Instruments SpectroSense 2+ spectrometer to determine the spectral characteristics of areas with a different degree of infestation with the common ragweed within the monitoring sites in Krasnodar Territory and Azov District of Rostov Province. These data were calibrated and used for identification of the ragweed spots in medium-resolution images obtained by Landsat 4–5 and Landsat 8 satellites in late August–early September of different years. It should be noted that such an approach does not allow one to state definitely that the weed spots revealed in the photographs consist of the common ragweed; instead, its results should be interpreted as the upper (i.e., overestimated) preliminary estimate of field infestation with the ragweed, which

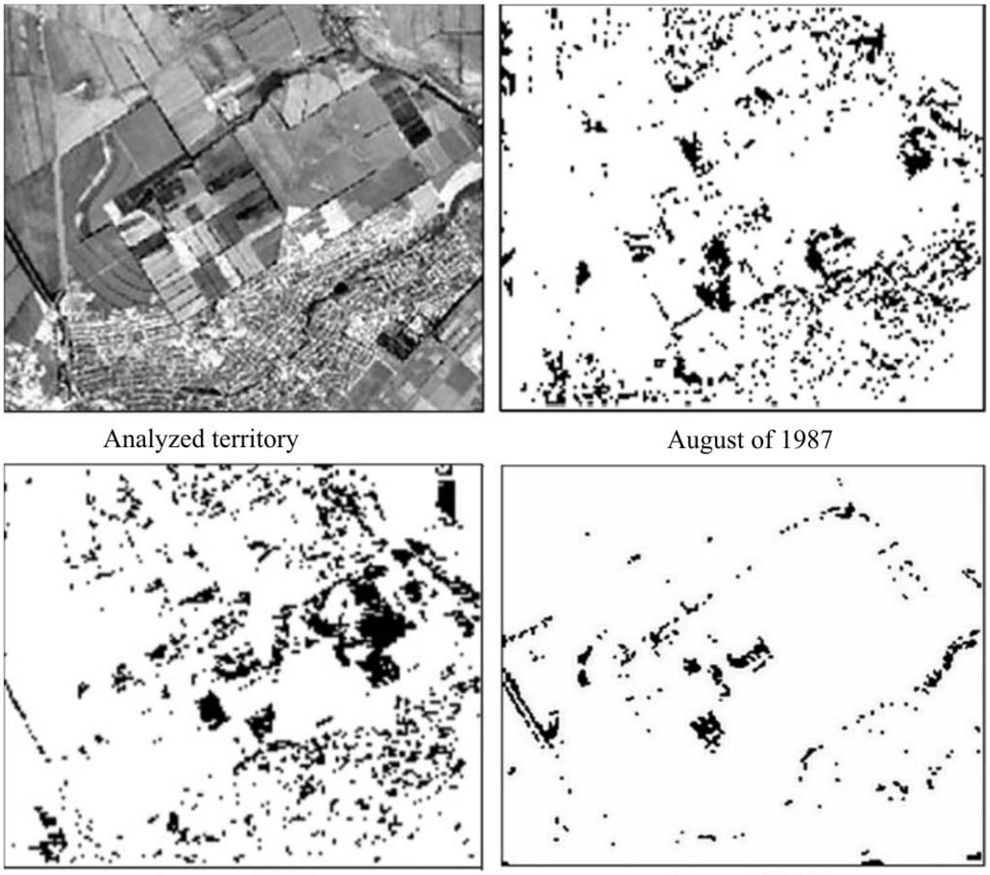

Fig. 6. Common ragweed infestation of the village Pelagiada and its environs (Stavropol Territory), where the leaf beetle was initially released in 1978.

may be then emended by hyperspectral analysis using the most informative channels and specialized processing algorithms to distinguish this weed species from other plants.

We analyzed the results of decoding the images which covered our monitoring plots. In particular, based of ERS data for 2009–2013, we mapped the common ragweed infestation pattern for Azov District of Rostov Province (Fig. 4). These maps did not reveal extended areas of complete infestation which had been typical of the early 1980s, similar to those shown in Figs. 2 and 3. The observed infestation spots were mostly located at roadsides and field edges; this distribution pattern was also confirmed by our field studies. The results obtained indicate that the recent field infestation data of Rosselkhoznadzor were considerably (several-fold) overestimated, which seems to result from the subjective assessment techniques used by the quarantine inspection workers.

The retrospective analysis of archival photographs of the Stavropol Territory made in the 1980s by the American satellites Landsat 4–5 shows that qualitative changes in agrophytocenoses related to the spatial distribution pattern of ragweed spots took place already in 1986, when the range of the ragweed leaf beetle exceeded 300 000 ha (Kovalev, 1989a). For example, infestation of a 7648-ha territory northeast of the village Pelagiada in the period between 1986 and 1988 is shown in Fig. 5. One may observe reduction of the infestation area during this period and also the inconsiderable number of fields totally infested with the common ragweed, although such fields were common in that territory in the preceding years (see Figs. 2, 3). These results agree well with the previous field research data which revealed a steep reduction of the number of ragweed seeds in the soil: from 24 000 seeds/m^2 in 1980 to 35 seeds/m^2 in 1985 (Kovalev and Vechernin, 1986, 1989; Kovalev, 1989a).

Fig. 6 presents the results of decoding of photographs made in 1987, 1988, and 2013 in the exact area where the leaf beetle was initially released in 1978.

Comparison of infestation maps based on archival and recent ERS demonstrates a high prolonged effect of the ragweed leaf beetle on agrophytocenoses: no extended foci of weed dominance, similar to those shown in Figs. 2 and 3, were revealed in either archival or recent photographs; the infestation spots are mostly seen at field edges and roadsides. This conclusion is confirmed by the results of analysis of the seed pool and seedling density of the common ragweed, and also by route surveys carried out during scientific expeditions in 2012–2013, in Rostov Province, the Republic of Adygeya, Stavropol and Krasnodar Territories (see Tables 1, 2; Kovalev et al., 2013).

The Tasks of the Modern Stage of Ragweed Control

In total, the results of field research and remote sensing data (reduction of the ragweed seed pool in the soil and areas of infested agrocenoses, as compared with the 1970s) testify to the large-scale effect of introduction of ragweed phytophages at the end of the 1970s, which has lasted for 30 years.

The results obtained not only show the achievements of biological control but also answer another question, a more important one in the opinion of Hoffmann and Moran (2008): what would be the state of things without application of this method?

The common ragweed has lost its position as the dominant weed. The small foci newly appearing due to soil devastation are quite easily suppressed by local chemical, mechanical, and agrotechnical methods, including rational crop rotation. This is an essentially new situation.

The statement of the result achieved is extremely important since it makes it possible to pass over to the tasks of the new stage of ragweed control. At present, the main harmful effect of this weed is its role in development of seasonal allergies (pollinosis, allergic rhinitis, and other diseases) in man (Ostroumov, 1989; Matishov et al., 2011).

The most important factor facilitating the establishment of the ragweed in phytocenoses is soil disturbance (MacDonald and Kotanen, 2010). Accordingly, the results of geobotanical descriptions show that to-date, *Ambrosia artemisiifolia* L. together with other ruderal flora prevails in uncultivated lands, pastures, abandoned land plots, and also in residence localities with neglected lawns and other greenery areas (Kovalev et al., 2013).

The biological ragweed control in urbanized territories requires development of new approaches, since the SPW of the leaf beetle is impossible there due to the limited foci and fairly low density of the weed. In particular, developing of methods of timely detection of ragweed foci based on satellite images seems promising. Work on optimization of mechanical and phytocenotic methods of local weed suppression should be continued (Matishov et al., 2011). In order to reduce the reproductive potential of the ragweed and concentration of its pollen in the air, work should be continued on introduction of specific North American phytophages previously selected by Kovalev (1989a), which are the only consumers of the ragweed generative organs: seeds (the fruit fly *Euaresta bella* Loew) and male inflorescences (the weevil *Trigonorhinus tomentosus* Say).

One more ragweed phytophage, the leaf beetle *Ophraella communa* LeSage, has recently become an object of active research. At the end of the 1990s this species was inadvertently introduced from North America into Japan and China where it was successfully acclimated and showed high efficiency of ragweed suppression (Yamanaka et al., 2007; Zhou et al., 2010). However, although development of this leaf beetle in nature is mainly associated with the common ragweed (Demovici, 2003), it is a polyphagous species which may also consume the leaves of the sunflower and crucifers. This leaf beetle has not yet been recorded in the territory of Russia, but its wide distribution in China and its recent finding in the north of Italy, not far from the Milan airport (Müller-Schärer et al., 2014) shows that its invasion into Russia is only a matter of time. In view of this, the ecological characteristics and potential harm of this species as well as prospects of its use as the ragweed control agent should be studied, including mathematical modeling and ERS data analysis.

CONCLUSIONS

(1) Biological suppression of extended foci of invasive weeds is possible only when the phytophagous insects originating from the native range of these weeds are used as control agents, since they are capable of forming solitary population waves (SPW) in their secondary ranges (Kovalev and Vechernin, 1986, 1989; Kovalev, 2004b; Kovalev et al., 2013).

(2) Successful application of the biological control method leads to a large-scale transformation of phytocenoses due to suppression of the dominant weed species and restoration of the natural succession in the territory affected by the phytophage SPW (Tyutyunov et al., 2013; Kovalev and Tyutyunov, 2014).

(3) The efficiency of the biological method of suppressing adventive weed plants by far surpasses that of the mechanical, chemical, and agrotechnical methods, which may have only a short-term local effect.

(4) Analysis of the causes of success or failure of large-scale projects of introducing biological agents to suppress invasive weeds is of both scientific and applied value for developing the theory and practice of the biological control method.

(5) There are objective reasons for underestimation of the efficiency of long-term biological control projects (McFadyen, 2000): insufficient financing, irregular distribution of funds among the work stages, gradualness and subjectivity of assessment of changes caused by the introduction of insect agents in large ecosystems, absence of protocols, photographs, and other means of recording the state of the ecosystem before the introduction, and complexity of ecosystem monitoring over several decades.

(6) Introduction of the ragweed leaf beetle *Zygogramma suturalis* F. in the South of Russia is a good example of a successful large-scale project whose effect has been preserved for thirty years after the phytophage release.

(7) Disappearance of a considerable ragweed phytomass observed in the fields before the introduction, a steep reduction of seed density in the soil (from 10 000–25 000 to 50–200 seeds/m^2), reduction of infestation areas, and absence of dense infestation foci in satellite images at present testify to the long-term efficiency of phytophage introduction and to the achievement of the main goal of these measures, namely suppression of the common ragweed in agrocenoses.

(8) The statement of efficiency of phytophage introduction is important for setting the tasks of the modern stage of ragweed control. At present, the common ragweed has lost its position of the dominant agricultural weed but still presents a serious problem as a synanthropic allergy-causing species in anthropogenically transformed territories.

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