

## Biological Control of *Ambrosia artemisiifolia* with Introduced Insect Agents, *Zygogramma suturalis* and *Epiblema strenuana*, in China

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*Ambrosia artemisiifolia* and *A. trifida* were found in 15 provinces in northeast, east and central China. Based on studies on distribution, habitat and growth characteristics of the 2 weeds, and a simulation of the effect of insect defoliators on the weed populations, a biological control program was started in 1987. Two insects, *Zygogramma suturalis* and *Epiblema strenuana*, were introduced from Canada, Russia and Australia, respectively, in 1987 and 1990. Results of host range tests in Beijing confirmed the host-specificity of *Z. suturalis* in China. Outdoor cage studies and indoor experiments showed that *Z. suturalis* attacked only *A. artemisiifolia*, and could produce good control of the weed. From 1988-91, 30,000 *Z. suturalis* were released. Establishment has been very low in Changsha (southern China) and Dandong (northeast China). When predators (spiders, manitids and kissing bugs) were removed from the cages in Beijing, the beetle increased to large populations. This suggests that population development of *Z. suturalis* in the field might have been hampered by the large predator population. *E. strenuana* attacked the 2 weeds and had potential to exert lethal stress. But uncertainty remains on its safe use in China as it could attack, develop and emerge from sunflower in cage tests. This result is in conflict with the tests conducted in Mexico and Australia as well as with the literature records in North America. Nevertheless, *E. strenuana* appeared to be a more effective biological control agent than *Z. suturalis*.

### Introduction

*Ambrosia artemisiifolia* L. and *A. trifida* L. (Asteraceae), 2 native American weeds now distributed world-wide, were probably introduced into China in the early 1930s. The earliest museum specimen of *A. artemisiifolia* was collected in 1935 in Hangzhou, Zhejiang Province. *A. trifida* was recorded in northeast China in 1959 (Huang 1987). The 2 weeds rapidly dispersed to northeast, north, east and south China. In infested areas, ragweeds form dense, monospecific communities. Not yet agricultural weeds in China, ragweeds are a major and increasing source of human allergies: the population incidence rate of pollen allergic fever in Shenyang city was 1.52% (Xia 1983).

Based on worldwide research on biological control of ragweeds (Harris and Piper 1970, Stegmaier 1971, Piper 1975, 1976, Goeden *et al.* 1974, Goeden and Ricker 1975a,b, 1976, Gilstrap and Goeden 1974, Batra 1979, Kovalev 1971, 1973, 1990, Kovalev and Cherkashin 1981, Kovalev, Cherkashin and Reznik 1983, Kovalev and Medvedev 1983, Kovalev and Runeva 1970, Kovalev, Runeva and Cherkashin 1983, Kovalev and Verchernin 1986, Reznik 1985a,b, Julien 1987, McClay 1987), a program of integrated management of the 2 weeds in China was initiated in 1987, with focus on use of biological control agents. A series of studies have been carried out on the distribution, habitat and growth characteristics of the 2 weeds, simulation of the effects of insect defoliators, replacement control with beneficial plants, and

biological control with insect agents (Wan 1989, Wan and Wang 1988a,b, 1991, Wan and Guan 1991, Wan and Wang 1990a,b,c,d, Guan *et al.* 1991 ). This report summarizes the main results of our studies to date.

### Distribution of the Weeds and Their Control Strategies in China

#### *Distribution and the Problem*

Our survey in 1987 showed that the 2 weeds were distributed in 15 provinces or cities, occurring mainly along railroads and highways in a recurrent "belt" pattern. *A. artemisiifolia* occurred throughout the northeast, north, south and east of China, infesting public parks, urban landscapes, residential communities, orchards, highway shoulders and agricultural fields. *A.*

*trifida* only occurred in northeast China (Fig. 1). In the heavily infested areas, ragweeds were often found in dense monospecific, communities, with an average community diversity index of 0.19, and an average of 1,686 seedlings/m<sup>2</sup> (range 552-3,740). The infestation of ragweed was not found to be a major agricultural problem, but was threatening to increase in importance. Heavy infestations damaged native plant communities, and caused economic losses in orchards and city landscape management. Hay fever, caused by pollen of the weeds, was becoming an increasing problem in heavily infested regions. A recent survey indicated that 1.52% of the population in Shenyang city was allergic to *Ambrosia* pollen (Xia 1983).

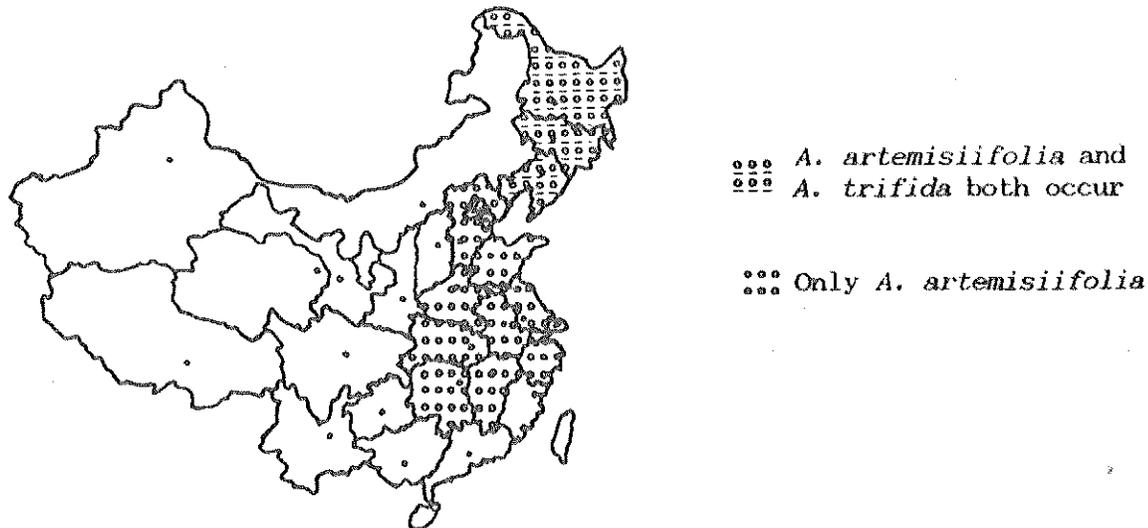


Figure 1. Distribution of *Ambrosia artemisiifolia* and *A. trifida* in China.

#### *Responses of Common Ragweed to Insect Defoliation Simulated by Artificial Defoliation*

Theoretically, defoliating biological weed control agents should exert their impact on the most vulnerable organ(s) and developmental stages of the host, without causing stimulating effects to the weed to offset the control effect. Field experiments were conducted in Shenyang in 1988 and 1989 to assess the impact of potential insect defoliators on common ragweed and on the physiological responses of the weed by means of artificial defoliation by cutting. Artificial cutting of 1/3, 2/3, 3/3, and a no-cutting control

of leaves were performed 1, 3 and 6 times throughout the growing season (Table 1). Results of the developmental measurements showed that the ragweed height in the untreated check was 223.3 cm, and the number of seeds was 1,873.2/plant. Cutting the leaves at the early vegetative growth stage reduced the seed production by >20%. When cut 3 times/season, the number of seeds was reduced by 26-70% (Table 2). No seed was produced when plants were cut 6 times/season.

Establishment of large numbers of insect defoliators early in the vegetative growth stage of a weed could exert great stress and result in

better control than if the defoliation occurred in the late, little-growing stages of the weed.

### Biological Control of *A. artemisiifolia* with Introduced Insect Agents

*Zygogramma suturalis* (Fabricius) (Coleoptera: Chrysomelidae)

Successful control of *A. artemisiifolia* was reported in the former USSR (Kovalev 1990, Kovalev & Cherkashin 1983, Kovalev, Cherkashin and Reznik 1983, Kovalev & Verchernin 1986). Two colonies of the insects were introduced into China from Canada and USSR in 1987 and 1988, respectively. After the introduction, host-specificity, biological and ecological characteristics and control effects of the beetle were studied Wan (1989).

**Host-specificity.** The host range of the beetle was retested in the laboratory with 72 plant species of crops, ornamental plants and closely related species, as well as the 2 ragweeds, representing 23 families. *Z. suturalis* was specific to *A. artemisiifolia* and did not feed on

any other plant tested. The beetle completed its life cycle on *A. artemisiifolia*. It is thus concluded that the insect is safe to be used for controlling ragweed in China (*et al.* 1989a).

**Biological and ecological characteristics.** In field and laboratory studies conducted in 1987-89 (Wan *et al.* 1989b), *Z. suturalis* had 3 generations/yr in the Beijing region. Overwintered adults resumed activity and began feeding in late April or early May. Adults of the 1st, 2nd and 3rd generations occurred in mid- to late-June, late July to early August, and early September, respectively. Under a constant 26°C, the average longevity of the female and male adults was 82.5 and 67.8 d. The mated females began ovipositing 16.5 d after their emergence from the soil. Oviposition lasted an average of 49.1 d with 394.5 eggs/female. Under the constant 16, 20, 24, 28 and 32°C, the developmental period of eggs was 8.9, 6.9, 5.4, 3.2 and 9.7 d; that of larvae was 22.2, 15.8, 13.0, 9.8 and 9.7 d; and 22.3, 16.4, 14.2, 10.1 and 8.7 d for the pupae, respectively.

**Table 1. Different dates, levels and times treated by leaf artificial defoliating.**

Date	Vegetative Stage	Physiological Age (d)	Artificial Cutting Level and Times											
			Plot No.											
			A	B	C	D	E	F	G	H	I	J	K	L
May 27	Initial growth	32	0	1	2	0	0	0	0	0	0	1	2	3
June 14	Peak growth	50	0	1	2	1	2	0	0	0	0	1	2	3
July 1	Initial bud	67	0	1	2	1	2	1	2	0	0	1	2	3
July 22	Full bud	78	0	0	0	1	2	1	2	1	2	1	2	3
July 27	Initial bloom	93	0	0	0	0	0	1	2	1	2	1	2	3
Aug 12	Full bloom	109	0	0	0	0	0	0	0	1	2	1	2	3

**Table 2. Comparison of seed production (number of seed/plant) between single leaf cutting and 3 cuttings.**

Level of Cutting	Time of Cutting (Physiological Days)/Level of Cutting							
	32-67		50-68		67-93		78-109	
	1/3	2/3	1/3	2/3	1/3	2/3	1/3	2/3
1 cutting	1,187.3	1,094.4	1,276.1	1,060.9	1,380.2	1,089.5	1,618.6	1,207.8
Seed production (%)	36.6	41.6	31.8	43.4	26.3	41.8	13.6	35.5
3 cuttings	1,010.7	550.0	866.9	613.3	702.7	646.7	1,413.9	885.9
Seed production (%)	46.0	70.6	53.7	67.2	62.4	65.5	24.5	52.7

The initiating temperature for egg, larval and pupal (development was 10.5, 11.1 and 6.9°C, respectively. The effective accumulative temperatures for eggs, larvae and pupae were

62.9, 178.9 and 219 day-degrees, respectively. The egg hatching rate was 76.7, 80 and 86%, respectively, under constant 28 and 32°C, and 20-27°C (the room temperature), respectively.

Under the rearing temperature of 16-28°C, larval and pupal survival rate varied between 61.5-75%. Survival of the 1st instar larvae was affected by low temperature, while high temperature influenced the survival rate of the 3rd and 4th instar. Humidity showed no significant effect on larval survival. Under 30-95% RH, the larval survival rate was between 57.2-60%.

Laboratory studies on some ecological characteristics of *Z. suturalis* were conducted during 1987-90. The total number of eggs laid by the experimental population of *Z. suturalis* was influenced by the rearing density in a parabolic pattern. The average fecundity of the females declined as the adult density increased in the containers of a fixed volume. A maximum of 386.7 eggs was obtained when 1 pair of adults were reared in a container of 7,238 cm<sup>3</sup> volume. When 18 and 25 adults were reared in these containers, each female laid 157.6 and 50.4 eggs, respectively. The mortalities of the larval and larval-pupal stages increased as the

rearing density increased. Yet the mortalities in each density treatment decreased in larger containers. Obviously, larval mortality was density-dependent. Food quality was found to be an important factor affecting larval survival. When larvae were fed with leaves from upper, middle and lower part of ragweed plants, the average survival rates were 90, 29.2 and 2.4%, respectively. Results of the larval consumption rate analysis showed that the accumulative consumption was 90.58 mg (fresh weight)/larva throughout the larval stage. Larvae 10-d-old had the highest consumption. The approximate digestibility (A.D.) declined and the efficiencies of conversion for ingested and digested food (E.C.J. and E.C.D., respectively) increased as the larvae developed (Table 3). The daily food consumption by mature adults was constant. Their A.D. was 64.2%. However, the daily food consumption by newly emerged adults was significantly greater than that by mature adults. Each adult consumed an average of 213.22 mg of fresh leaves before oviposition.

**Table 3. Larval body weights and food consumption (dry weight, mg) and utilization ratio for food (%).**

Parameter	Physiological Age (d)					
	2	4	6	8	10	12
Body weights	0.15	0.40	1.20	2.38	6.00	8.19
Food consumption (FD)	1.47	2.10	3.07	3.65	5.80	2.43
FD accumulation	1.47	3.57	6.64	10.29	16.09	18.53
Approximate digestibility (AD)	97.3	96.2	94.1	84.1	81.7	71.2
Efficiency of conversion						
Ingested food (E.C.J.)	7.9	12.6	29.4	36.8	88.9	92.3
Digested food (E.C.D.)	7.7	12.1	27.7	30.9	72.6	65.7

Long-term storage at low temperature influenced the survival and fecundity of the overwintered adults. The survival rate varied between 11.9-31.1%, when adults underwent storage under 4-6°C for 57-146 d. The survival rate curve followed Deevey's III type. Each individual laid 118 and 68.6 eggs after being kept under 4-6°C for 92 and 146 d, respectively. The oviposition peak after storage occurred earlier in comparison with those not stored.

*An experimental population life table.* The life table of *Z. suturalis* was constructed based on the laboratory studies conducted during 1987-88. The experimental population with sufficient food supply multiplied 59 times under

constant 26°C. The population intrinsic rate of increase was 0.06772. The instantaneous birth rate and death rate were 0.36157 and 0.29386, respectively. The average developmental period for 1 generation was 66.5 d. The survival rate curve fitted into Deevey's II type. The female age-specific survival rate fitted Deevey's I type. The egg, larva, pupa and adult accounted for 37.44, 45.08, 12.05 and 5.43, respectively, of the theoretically stable population of the species.

*A cage study on the effects of A. artemisiifolia.* Outdoor-cage studies were conducted in Beijing in 1988 on the control effects of common ragweed with *Z. suturalis*.

Introduction of 2, 1st instar larvae on 1 ragweed seedling at its 4-leaf stage resulted in optimal control. By maturation of the larvae, 95.7% of the host leaves were destroyed. The adult control effects improved as density of the adults introduced into a plot increased. When 65 adults were introduced into a plot of 12 host

plants with 10 leaves each, 81.2% of the leaves were destroyed after 24 d. In the following year, the number of germinated host plants in the adult-controlled plot was only 3.7 times that in the previous autumn, compared with the reproduction rate of 33.8 times in the control plot with no beetles (Table 4).

**Table 4. Effects on *A. artemisiifolia* and seedling numbers in May of the following year with *Z. suturalis* in plots.**

Number of Adults Released	% Leaves Destroyed	Number of Host Seedlings Germinated in the Following Year (means $\pm$ SD)	% Increase in Ragweed Populations
Check	0	406.0 $\pm$ 12.3	33.8
10	14.0	369.3 $\pm$ 31.6	30.8
20	20.0	281.7 $\pm$ 28.2	23.5
40	57.0	171.3 $\pm$ 27.2	14.3
65	81.2	44.3 $\pm$ 4.9	3.7

The consumption rate by adults was a constant 0.067%/adult/d. No population interference was observed when adults aggregated on the hosts. An integrated fuzzy judgment model was proposed for evaluation of the control effects by *Z. suturalis*. The model was thought to be comprehensive, flexible, and practical (Wan and Wang 1991).

*Results of releasing Z. suturalis.* All the above laboratory experiments suggested that the beetle would be a promising natural enemy against *A. artemisiifolia*. During 1988-91, a total of 30,000 beetles were released in Changsha (Southern China), Nanning (southeast China), Tieling, Shenyang and Dandong (northeast China). To date, only low number recoveries were obtained in Changsha and Dandong, while no recoveries have been made in Nanning, Tieling and Shenyang. However, the beetle developed a large population in Beijing under the protected conditions. Some experiments are being conducted to identify the stress factors affecting the population. It seemed that predators such as spiders, manitids, and kissing bugs, which prey on eggs and larvae, even the adults of the beetle, formed a major suppressing factor to the beetle's population.

*Epiblema strenuana* (Walker) (Lepidoptera: Tortricidae)

*E. strenuana*, a native American gall-former, is reported to have a wide distribution in its native habitat. No species of *Epiblema* is recorded as an agricultural pest, nor from sunflower, *Helianthus annuus* L. (Asteraceae), in the literature and in Mexico (McFadyen 1985, McClay 1987). The adults are nocturnal and inactive during the day unless disturbed. Larvae bore into the plant from their initial feeding sites, around which swelling soon takes place and a fusiform gall is formed, and can transfer into another plant even in the later instars. *E. strenuana* overwinters as mature larvae in host plants and breeds continuously in winter in a greenhouse as long as the host plant is available in suitable conditions (unpublished data). The moth has been used for successful control of *Parthenium hysterophorus* L. (Asteraceae) in Australia (McFadyen 1985).

*Host-specificity.* Host plants recorded in North America of all species of *Epiblema* are in Compositae, with many restricted to a single host genus or species. Within the Compositae, most of the hosts belong to the tribe Heliantheae, with several in the Astereae. All the species attacking Compositae are root- or stem-borers (McClay 1987, McFadyen 1985). The hosts recorded for *E. strenuana* are *Ambrosia* spp., *P. hysterophorus*, *Xanthium* spp. *Chenopodium album* (McClay 1987).

McClay (1987) first conducted tests on larval feeding of *E. strenuana* with 14 plant species

and a multiple-choice oviposition test on 11 plant species. He reported that the moth had a restricted host range and would not attack any plant of economic importance within Asteraceae. McFadyen (1985) conducted a detailed testing with 51 plant species, including 3 sunflower cultivars, and concluded that *E. strenuana* only attacked *P. hysterophorus*, *A. artemisiifolia*, and *Xanthium strumarium* L.

*Host-specificity testing in China in 1990 and 1991.* *E. strenuana* was introduced from Alan Fletcher Research Station, Queensland Department of Lands, Australia, into China in 1990. Following the introduction, the host range of the moth was retested in outdoor cages in Beijing in 1990 and 1991.

No-choice and multiple-choice tests were conducted in cages (40 x 35 x 50 cm), with 37 species in 15 families. In the multiple-choice tests, each cage contained 4 test species with *A. artemisiifolia*, replicated 3 times. In the no-choice test, each cage contained only 1 tested species, and was replicated 2 times. Results of this year's tests concurred with those of McClay (1987) and McFadyen (1985).

In August 1991, a no-choice test with 3 replications was carried out to confirm if *E.*

*strenuana* fed on sunflower, which is the only important economic plant within Asteraceae in China. A local sunflower cultivar (13 plants with an averaged height of 25 cm) was exposed to 3 pairs of newly emerged adults in each replication. Two of 13 plants were bored by the larvae in 1 replication but no boring occurred in the other replications. A further choice test was conducted in the greenhouse to confirm if the insect could complete its life cycle on sunflower. Three plant species were used: *A. artemisiifolia*, *P. hysterophorus* and *H. annuus* (Table 5).

The result revealed that *E. strenuana* could attack, develop and emerge from sunflower, although it was obvious that sunflower was not a preferred host. Another experiment in which larvae of *E. strenuana* were introduced onto sunflower showed that 1st, 2nd and 3rd instar larvae could transfer onto and bore into the plants. These results conflict with results from tests conducted in Mexico and Australia, as well as with literature records. The reproductive capacity of adults from sunflower, and survival capacity of progeny, however, have not been determined. A large experiment with different varieties of sunflower are currently being conducted in greenhouse and field cages.

**Table Results of host-specificity testing of *E. strenuana*.**

Test Species	Number of Plants Tested	Number of Test Plants Attacked	Ratio (%)	Number of Adults Emerged
<i>Helianthus annuus</i>	188	13	6.9	7
<i>Ambrosia artemisiifolia</i>	126	103	81.7	151
<i>Parthenium hysterophorus</i>	98	81	82.7	112

### Conclusions

*Z. suturalis* can be used safely against *A. artemisiifolia*. Efforts should be made resolve the limiting factors, for the beetle to establish in different climates.

*E. strenuana* can attack *A. artemisiifolia* and *A. trifida*, and exert considerable stress on the 2 weeds. However, the safety of *E. strenuana* has not yet been determined for use in China. Although the moth could attack, develop and emerge from sunflower, the host utilization of the moth can largely depend upon whether its progeny have a capacity to survive in sunflower, as the moth does not appear to prefer feeding on sunflower to its original hosts.

Several other *Ambrosia* insects (*Euaresta* spp., Phalonidae sp., *Liothrips* sp., and a seed weevil) were introduced in October 1991 from the Regina Research Station, Agriculture Canada. These insects are currently being reared in quarantine, and the host-specificity will also be tested.

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## References

- Batra, S.W.T. 1979. Reproductive behavior of *Euresta bella* and *E. festiva*, potential agents for the biological control of adventive North American ragweeds (*Ambrosia* spp.) in Eurasia. *New York Entomological Society LXXXVII*(2):118-25.
- Gilstrap, F.E. and R.D. Goeden. 1974. Biology of *Tarachidia candefacta*, a Nearctic noctuid introduced into the U.S.S.R. for ragweed control. *Annals of the Entomological Society of America* **67**(2):265-70.
- Goeden, R.D., O.V. Kovalev and D.W. Ricker. 1974. Arthropods exported from California to the USSR for ragweed control. *Weed Science* **2**(2):156-8.
- Goeden, R.D. and D.W. Ricker. 1975a. The phytophagous insect faunas of ragweed, *Ambrosia acanthicarpa*, in southern California. *Environmental Entomology* **3**(2):327-34.
- Goeden, R.D. and D.W. Ricker. 1975b. The phytophagous insect faunas of ragweed, *Ambrosia confertiflora*, in southern California. *Environmental Entomology* **4**(2):301-6.
- Goeden, R.D. and D.W. Ricker. 1976. The phytophagous insect faunas of ragweed, *Ambrosia chenoposiifolia*, *A. erocentra* and *A. ilicifolia*, in southern California. *Environmental Entomology* **5**(5):923-30.
- Guan, G.Q., S.D. Li, D.C. Gao, Q. Zhai, F.H. Wan, R. Wang and W.Q. Luo. 1991. Effect of defoliation on growth and fruiting of ragweed. *Chinese Journal of Applied Ecology* **2**(4):292-7 (in Chinese).
- Harris, P. and G.L. Piper. 1970. Ragweed (*Ambrosia* spp., Compositae): Its North American insects and the possibilities for its biological control. *CIBC Technical Bulletin* **13**:117-40.
- Huang, B. 1987. Damages of ragweed and its control. Science Press, Beijing, 74 p. (in Chinese).
- Julien, M.N. 1987. *Biological Control of Weeds: A World Catalogue of Agents and Their Target Weeds*. CAB International Institute of Biological Control.
- Kovalev, O.V. 1971. Insects feeding on ragweeds (*Ambrosia* L.) in North America and their application in biological control of this weed in USSR. *Zoologicheskii Zhurnal* **50**(2):199-209 (in Russian).
- Kovalev, O.V. 1973. Modern outlooks of biological control of weed plants in the USSR and the international phytophagous exchange. *Proceedings of the II International Symposium on Biological Control of Weeds*, pp. 166-72.
- Kovalev, O.V. 1990. New factors of efficiency of phytophages: a solitary population wave and succession process. *Proceedings of the VII International Symposium on Biological Control of Weeds*, 6-11 March 1988, Rome, Italy. Delfosse, E.S. (ed.). Ministero Dell'Agricoltura E Delle Foreste, Rome/CSIRO, Melbourne, Australia, pp. 51-3.
- Kovalev, O.V. and V.N. Cherkashin. 1981. Acclimatization of ambrosia insect. *Zashchita Rastenii* **10**:21 (in Russian).
- Kovalev, O.V. and V.N. Cherkashin. 1983. Effectiveness of the ambrosia leaf beetle. *Zashchita Rastenii* **2**:10-1. (in Russian).
- Kovalev, O.V., V.N. Cherkashin and S.Y. Reznik. 1983. Preliminary methodological guidelines for the use of leaf beetles of the genus *Zygogramma* Chev. (Coleoptera, Chrysomelidae) in the biological control of ragweed (*Ambrosia artemisiifolia* L., *A. psilostachya* D.C.). Leningrad (in Russian).
- Kovalev, O.V. and L.N. Medvedev. 1983. Theoretical bases of the introduction of ragweed leafbeetles of the genus *Zygogramma* Chev. (Coleoptera, Chrysomelidae) into the USSR for the biological control of ragweed. *Entomologicheskoye Obozrenie* **62**(1):17-32. (in Russian).
- Kovalev, O.V., S.Y. Reznik and V.N. Cherkashin. 1983. Methodological peculiarities of the use of leaf beetles of genus *Zygogramma* Chev. (Coleoptera, Chrysomelidae) in the biological control of ragweed (*Ambrosia artemisiifolia*; *A. psilostachya* D.C.). *Entomologicheskoye Obozrenie* **62**:404-8. (in Russian).
- Kovalev, O.V. and T.D. Runeva. 1970. The noctuid *Tarachidia candefacta* Hubn. (Lepidoptera, Noctuidae) – a promising phytophagous insect for the biological control of weeds in the genus *Ambrosia* L. *Entomologicheskoye Obozrenie* **49**(1):23-36. (in Russian).
- Kovalev, O.V. and V.V. Verchernin. 1986. Description of a new wave process in populations with reference to introduction and spread of the leaf beetle, *Zygogramma suturalis* F. (Coleoptera: Chrysomelidae). *Entomologicheskoye Obozreniye* **1**:21-38. (in Russian).
- McClay, A.S. 1987. Observations on the biology and host specificity of *Epiblema strenuana* (Lepidoptera, Tortricidae) a potential biocontrol agent for *Parthenium hysterophorus* (Compositae). *Entomophaga* **32**(1):23-4.
- McFadyen, R.E. 1985. The Biological control programme against *Parthenium hysterophorus* in Queensland. *Proceedings of the VI International Symposium on Biological Control of Weeds*, Vancouver, Canada. Delfosse, E.S. (ed.). Agriculture Canada, pp. 789-96.
- Piper, G.L. 1975. The biology and immature stages of *Zygogramma suturalis*. *Ohio Journal of Science* **75**(1):19-24.
- Piper, G.L. 1976. Bionomics of *Euarestoides acutangulus* on common ragweed in northeastern Ohio. *Ohio Journal of Science* **78**(6):304-9.
- Reznik, S. Ya. 1985a. Factors determining selectivity during oviposition of ragweed flea beetle (*Zygogramma*

- suturalis*). *Zoologicheskii Zhurnal* **44**:234-44 (in Russian).
- Reznik, S. Ya. 1985b. Oviposition by the striped ambrosia beetle. *Zashchita Rastaeii* **5**:35-6 (in Russian).
- Stegaier, C.E., Jr. 1971. Lepidoptera, Diptera, and Hymenoptera associated with *Ambrosia artemisiifolia* in Florida. *The Florida Entomologist* **54**(3):259-72.
- Wan, F.H. 1989. Biological control of *Ambrosia artemisiifolia*, with a potential biological control agent, *Zygogramma suturalis*. Ph.D. thesis, Graduate School, CAAS, China, 191 p.
- Wan, F.H. and G.Q. Guan. 1991. An analysis of the weed growth of *Ambrosia artemisiifolia* and integrated management strategies. In: *Advances in Ecology--Proceedings of the Fourth Congress of the Ecological Society of China*. China Science and Technology Press, pp. 141-2.
- Wan, F.H. and R. Wang. 1988a. Preventing the damages from common ragweed *Ambrosia artemisiifolia*. *News of Agricultural Science and Technology* **10**(433):2-3.
- Wan, F.H. and R. Wang. 1988b. The distributions, damages and control of common ragweed, *Ambrosia artemisiifolia*, in China. *Bulletin of Agricultural Science and Technology* **5**:24-5.
- Wan, F.H. and R. Wang. 1990a. A cage study on the control effects of *Ambrosia artemisiifolia* by the introduced biological control agent, *Zygogramma suturalis*. *Chinese Journal of Biological Control* **6**(1):8-12.
- Wan, F.H. and R. Wang. 1990b. A general situation of biological control of *Ambrosia artemisiifolia*. *Weed Science* **1**:33-5.
- Wan, F.H. and R. Wang. 1990c. Biological and ecological characters of a malignant weed, *Ambrosia artemisiifolia*. *Journal of Weed Science* **4**(1):45-8.
- Wan, F.H. and R. Wang. 1990d. Survival rates and fecundity of *Zygogramma suturalis* (Col.: Chrysomelidae) after low temperature storage. *Chinese Journal of Biological Control* **6**(4):145-7.
- Wan, F.H. and R. Wang. 1991. Laboratory bionomical studies on *Zygogramma suturalis* (Col.: Chrysomelidae). *Acta Ecologica Sinica* **11**(3):232-6.
- Wan, F.H., R. Wang and S.B. Qiu. 1989a. Host-specificity tests of *Zygogramma suturalis* (Col.: Chrysomelidae): An important biological control agent of *Ambrosia artemisiifolia*. *Chinese Journal of Biological Control* **5**(1):20-3.
- Wan, F.H., R. Wang and S.B. Qiu. 1989b. Biology of *Zygogramma suturalis* (F.) (Col.: Chrysomelidae), an introduced biological control agent of *Ambrosia artemisiifolia*. *Chinese Journal of Biological Control* **5**(2):71-75.
- Xia, F.Y. 1983. Allergic disease of ragweed pollen. *Plant Quarantine* **6**:16-9.