ISSN 0013-8738, Entomological Review, 2018, Vol. 98, No. 6, pp. 663–673. © Pleiades Publishing, Inc., 2018.
Original Russian Text © I.G. Bokina, 2018, published in Entomologicheskoe Obozrenie, 2018, Vol. 97, No. 3, pp. 364–379.

Predatory Lady Beetles (Coleoptera, Coccinellidae) in Cereal Agrocenoses in the Northern Forest-Steppe of West Siberia and the Influence of Agrotechnical Methods on Them

I. G. Bokina

Siberian Institute of Agriculture and Chemicalization, Novosibirsk Province, Krasnoobsk, 630051 Russia

e-mail: irina.bokina@mail.ru

Received March 19, 2015, in final form, June 25, 2018

Abstract—Predatory lady beetles (Coccinellidae) form one of the prevalent and effective groups of entomophages in the forest-steppe zone of West Siberia. Among 17 species of predatory lady beetles recorded in cereal agrocenoses and on bird cherry trees, *Propylea quatuordecimpunctata*, *Coccinella septempunctata*, *Hippodamia tredecimpunctata*, *H. variegata*, and *H. arctica* are predominant. This paper presents data on the species composition and ecological features of lady beetles in agrocenoses of winter rye, spring wheat, and oats as well as on the impact of agrotechnical methods (the main treatment of soil, application of chemicals, and forecrops) and cultivation technology on the abundance of lady beetles.

DOI: 10.1134/S0013873818060027

There is extensive literature devoted to predatory insects, including lady beetles (Coccinellidae) (Telenga, 1948; Semyanov, 1984; Voronin et al., 1988; Mokhrin, 2009; Michels et al., 2001; Evans, 2003; *Ecology and Behaviour*…, 2012, and many others). Data on the predatory lady beetles inhabiting cereal agrocenoses in West Siberia are to be found in the works of Klementyeva (1961), who recorded 2 species of Coccinellidae in Omsk Province, Savoiskaya (1961) and Filatova (1965), who recorded 7 species each, Aleeva and Babushkina (1977), who recorded 6 species, and Semenov (1982), who listed 9 species of Coccinellidae for the southeast of Altai Territory.

In the forest-steppe of West Siberia, aphids constitute the main food source of lady beetles in cereal fields. The most common aphid species are the grain aphid *Sitobion avenae* F. and the bird cherry-oat aphid *Rhopalosiphum padi* L.; besides, the hedgehog grain aphid *Sipha* (*Rungsia*) *maydis* P. has recently become more abundant (Bokina, 2012). Earlier, 17 species of Coccinellidae were recorded as entomophages of these aphids (Krotova, 1990).

Lady beetles are characterized by high abundance, high searching capacity, the abilities to migrate over considerable distances in search of food, concentrate in areas of high density of pests, and suppress the pest outbreaks; high voracity combined with resistance to starvation and the ability to feed, under unfavorable conditions, on pollen, nectar, plant sap, fungi (powdery mildew), and various soft-bodied insects, these features allowing lady beetles to survive under critical conditions detrimental to other entomophages; high fecundity and considerable potential rates of population growth; ecological plasticity, allowing them to occupy a variety of biotopes (Meier, 1940; Yablokov-Khnzorian, 1970; Kuznetsov, 1973; Savoiskaya, 1983, 1991). All these features set lady beetles apart from other predatory entomophages.

This work continues our research of the fauna and ecological features of Coccinellidae and the impact of agrotechnical methods and cereal cultivation technology on their abundance.

MATERIALS AND METHODS

Research was carried out in 1986–1993, 1998–2000, and 2005–2007 at Elitnoe experimental farm (Novosibirsk District, Novosibirsk Province), located in the northern forest-steppe zone of West Siberia. The abundance, species composition, and specific biological features of lady beetles were studied during the vegetation season in commercial cereal crops: winter rye, spring wheat, and oats. Insects were collected by 20–30 standard net-sweeps at 10 sites within each crop, once every 1–2 weeks. For comparability, the data were recalculated per 100 net-sweeps. The number of aphids and adults and larvae of Coccinellidae

was determined for each survey and for the whole vegetation season. The relation between the abundance of aphids and that of lady beetles was assessed by correlation analysis. The species composition of lady beetles was also determined in spring wheat fields in Kochkovsky and Krasnozersky districts of Novosibirsk Province. The long-term mean accumulated temperatures above +5…+10°C in Novosibirsk District are 1840–2000°, those above +10…+12°C are 1570–1750°; the long-term mean annual precipitation is 390–450 mm. The corresponding parameters for Kochkovsky District are 1840–2000, 1570–1750°C, and 330–390 mm; those for Krasnozersky District are 1910–2000, 1660–1750°C, and 290–340 mm (*Adaptive-Landscape Agriculture*…, 2002). Besides cereal crops, insects were surveyed on bird cherry trees growing in steppe forest patches and forest shelter belts. Species of Coccinellidae were identified using collection material previously identified by G.I. Savoiskaya (Kazakhstan Research Institute for Plant Protection and Quarantine, Almaty) and V.P. Semyanov (Zoological Institute, Russian Academy of Sciences, St. Petersburg).

For biological studies, lady beetles at all stages of development were collected in the fields. The preimaginal stages were kept singly in Petri dishes until emergence of adults; the duration of development was recorded. To determine their voracity, larval and adult lady beetles were fed on adults or late instar nymphs of the grain or bird cherry-oat aphids, which were provided in excess. The experiments were carried out in 15 replicates.

The effects of the methods of spring wheat cultivation on Coccinellidae were studied during the long-term stationary experiments at the Siberian Institute of Agriculture and Chemicalization. The effects of the tillage variant, pesticide application, and the culture preceding wheat in the crop rotation scheme (fallow, wheat, wheat, oats, wheat) were assessed in the first experiment in 1992–1993. The test plots were 130 m^2 in area. The tests were carried out in three replicates. The abundance of aphids and their predators was assessed in wheat grown after fallow and as the 4th crop after fallow, without tillage and in three variants of tillage: plowing (25–27 cm deep for the 3rd and 4th crops after fallow, 20–22 cm deep in other cases), deep cultivation (25–27 cm deep for the 3rd and 4th crops after fallow, 20–22 cm deep in other cases), and sweep cultivation (12–14 cm deep). Three variants of chemical treatment were tested: without fertilizers or pesticides, with fertilizers only (phosphorus in effective dosage of 120 kg/ha at fallow termination, nitrogen in effective dosage of 60 kg/ha before the 2nd and 3rd crops, nitrogen in effective dosage of 80 kg/ha before the 4th crop), and with a complete set of chemicals (fertilizers as in the preceding variant; herbicides, fungicides, and insecticides according to the actual phytosanitary situation in agrocenoses). In 1992, wheat was treated with Puma Super 7.5 herbicide (1 l/ha) at the stage of 2–3 true leaves, with 2,4-DA herbicide (2 l/ha) mixed with CCC 460 growth regulator (2 l/ha) at the tillering stage, and with Tilt fungicide (0.5 l/ha) at the early heading stage. In 1993, wheat was treated with Puma Super 7.5 (1 l/ha) and Granstar (25 g/ha) herbicides and with CCC 460 growth regulator (2 l/ha) at the tillering stage and with mixture of Bayleton fungicide (1 kg/ha) and Fastac insecticide (0.1 l/ha) at the flag leaf and early heading stage. The insecticide was used against the wheat thrips *Haplothrips tritici* (Kurd.).

In the second experiment in 1998–2000, the effect of forecrops on the abundance of Coccinellidae and cereal aphids in wheat fields was studied in three cereal crop rotation systems (vetch-oat intercrop, wheat, wheat, barley; rape, wheat, wheat, barley; wheat, oats, wheat, barley), two cereal-fallow systems (fallow, wheat, wheat, barley; fallow, winter rye, wheat, barley), and one cereal-grass system (melilot, winter rye, wheat, barley), and also in fields of wheat and alfalfa grown without rotation. Fertilizers were applied in autumn before tillage. Phosphoric fertilizers were used in effective dosage of 30 kg/ha per crop. The annual effective dosage of nitrogenous fertilizer before wheat after all the forecrops except fallow was 60 kg/ha. Treatment with herbicides and fungicide was carried out according to the actual phytosanitary situation. The insecticide (Fastac, 0.1 l/ha) was used in 1999 during the wheat tillering stage, in tank mixture with herbicides. The area of fields in crop rotation was 475 m^2. The tests were carried out in three replicates. Insects were surveyed in wheat grown as the 1st and 2nd crops after fallow, in wheat crops after winter rye, oats, vetch-oat intercrop, barley, and rape, in wheat cultivated for several years without rotation, in all the forecrops, and also in barley-melilot intercrop and in permanent alfalfa.

In 2005–2007, the effect of cultivation methods of spring wheat (Novosibirskaya 29 variety) on cereal aphids and predatory insects was assessed. Three methods were studied: (1) extensive (control), without

any chemical treatment; (2) normal, including application of fertilizers (phosphorus in effective dosage of 20 kg/ha with row application at sowing) and herbicides against dicot weeds (in 2006, 0.6 l/ha of Dialen Super; in 2005 and 2007, 0.7 l/ha of Elant); (3) intensive, which included, besides the components of the normal method, also seed treatment (Raxil, 1.5 l/ton), application of nitrogenous fertilizer before sowing according to soil diagnostics, application of herbicide against monocot weeds (0.5 l/ha of Puma Super 100), fungicide (in 2005–2006, 0.6 l/ha of Falcon; in 2007, 0.5 l/ha of Tilt), growth regulator (in 2007, 1.5 l/ha of CCC 460), and when needed, insecticide against culm pests (in 2006, 0.25 l/ha of Decis; in 2007, 0.05 l/ha of Decis Extra) used at the stage of 2–3 true leaves. The test plots were 2070 m^2 in area; the experiments were carried out in 3 replicates with a systematic arrangement of the variants.

The pests and beneficial insects were surveyed in the experimental fields during the vegetation season by 10–30 standard net-sweeps for each variant every 7–10 days, in 3 or 4 replicates. The data were recalculated per 10 or 50 net-sweeps.

The results were statistically processed by correlation analysis and by one-way or multi-way ANOVA; 95% confidence intervals were determined for the mean abundance values.

RESULTS AND DISCUSSION

Of the predatory entomophages, lady beetles are among the first to appear on spring cereal crops, and they also remain prevalent there for almost the entire vegetation season. For instance, in the years of our research the abundance of Coccinellidae varied during vegetation from 33% in the wheat stand and from 40% in the oat agrocenosis to 100% of the total abundance of predatory entomophages. During the period of the highest pest density, Coccinellidae comprised 29–70 and 33–91% of the total abundance of predatory entomophages in the wheat and oat agrocenoses, respectively. For the whole vegetation season, lady beetles comprised 28–64% of the total number of predators on wheat and 52–82% on oats. In some infrequent seasons the fraction of lady beetles did not exceed 11% at the highest pest density and 14% for the whole vegetation season. Strong positive correlations were observed between the abundance of cereal aphids and that of predatory lady beetles in the spring cereal agrocenoses, both for the period of the highest density of pest populations (r = +0.93) and for the whole vegetation season (r = +0.89).

In winter rye fields lady beetles were prevalent till mid-July, when they comprised 48–82% of the total abundance of predators. Later in the season, predatory damsel bugs of the genus *Nabis* became the most abundant whereas the fraction of lady beetles decreased to 1–20%. Correspondingly, the correlation between the abundance of lady beetles and that of cereal aphids in the winter rye agrocenosis was weaker (r = +0.59). Lady beetles comprised 12–68% of the total abundance of predatory entomophages at the peak of the aphid density, and 11–70% for the whole season.

In Kochkovsky District of Novosibirsk Province, slightly differing from Novosibirsk District in heat provision and precipitation, Coccinellidae were dominant in wheat crops (45%) and comprised up to 26% of the total abundance of predators in the oat agrocenosis. In Krasnozersky District, having a warmer and drier climate, the prevalent predators in wheat crops were more thermo- and xerophilous damsel bugs and lacewings, whereas lady beetles comprised no more than 11% of the total abundance of predatory entomophages.

Of the recorded lady beetles, seven species prefer woody vegetation, including bird cherry trees where they feed on the bird cherry-oat aphid: *Calvia quatuordecimguttata* L., *C. decemguttata* L., *Coccinella quinquepunctata* L., *C. hieroglyphica* L., *Adalia bipunctata* L., *Anatis ocellata* L., and *Harmonia axyridis* Pall. These species appear in cereal fields either occasionally or in case of food shortage in their principal habitats. Their abundance on the studied cereal crops was no more than 0.5–1% of the total abundance of Coccinellidae. At the same time, other authors did record the development of *Calvia decemguttata* and *Harmonia axyridis* in agrocenoses (Kuznetsov, 1993). During the season lady beetles may change habitats within the biotope and also migrate to different biotopes (Savoiskaya, 1983). Such species as *Coccinella trifasciata* L., *Coccinula quatuordecimpustulata* L., *C. sinuatomarginata* Fald., *Hippodamia variegata* Goeze (= *Adonia variegata*), *H. arctica* Schneider (= *Adonia amoena* Fald.), *H. septemmaculata* De Geer, and *Anisosticta novemdecimpunctata* L. are hortobionts, and they were recorded by us in cereal fields. In spring, adults of *H. arctica* and *H. variegata* occur in small quantities in aphid colonies on bird cherry.

Table 1. Relative abundance of adults of the family Coccinellidae in the spring wheat agrocenosis during the vegetation season (means, ind./100 net-sweeps)

Species	1987		1988		1991		1992		1993		1998		1999		2000		2007	
	ind.	%	ind.	%	ind.	%	ind.	%	ind.	%	ind.	%	ind.	%	ind.	%	ind.	%
Coccinella septempunctata	61	25.1	81	32.4	20	20.2	64	8.0	16	12.5	13	6.5	1	1.7	13	2.6	2	1.2
C. trifasciata	1.5	0.6	5	2.0	0	0.0	23	2.9	0	0.0	1	0.5	0	0.0	10	2.0	1	0.6
Propylea quatuordecim-punctata	105.5	43.4	72	28.9	6	6.1	341	42.6	40	31.3	103	51.5	46	76.7	233	47.0	77	47.5
Hippodamia variegata	0	0.0	0	0.0	54	54.5	29.5	3.7	4	3.1	20	10.0	3	5.0	136	27.4	20	12.3
H. arctica	0.5	0.2	2.5	1.0	17	17.2	308.5	38.5	60	46.9	46	23.0	10	16.7	63	12.7	18	11.1
H. tredecim-punctata	73	30.0	87.5	35.2	1	1.0	35	4.4	8	6.3	10	5.0	0	0.0	40	8.1	43	26.5
H. septem-maculata	1	0.4	0	0.0	0	0.0	0	0.0	0	0.0	6	3.0	0	0.0	0	0.0	0	0.0
Anisosticta novemdecim-punctata	0	0.0	0.5	0.2	0	0.0	0	0.0	0	0.0	1	0.5	0	0.0	1	0.2	1	0.6
Coccinula sinuato-marginata	0	0.0	0.5	0.2	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
C. quatuor-decimpustulata	0.5	0.2	0	0.0	1	1.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Total, ind.	243 ± 29.8		249 ± 50.9		99 ± 9.2		801 ± 72.1		128 ± 23.2		200 ± 20.5		60 ± 7.2		496 ± 54.5		162 ± 18.3	

In 1991, surveys were conducted in Kochkovsky District.

Table 2. Relative abundance of adults of the family Coccinellidae in the oat agrocenosis during the vegetation season (means, ind./100 net-sweeps)

Species	1986		1987		1998		1999		2000	
	ind.	%	ind.	%	ind.	%	ind.	%	ind.	%
Coccinella septempunctata	29.5	11.3	34.5	34.8	3	10.0	0	0.0	30	17.3
C. trifasciata	3	1.2	1	1.0	0	0.0	1	5.9	1	0.6
Propylea quatuordecimpunctata	80	30.7	29.5	29.8	17	56.7	10	58.8	50	28.9
Hippodamia arctica	3	1.2	0.5	0.5	7	23.3	3	17.6	23	13.3
H. variegata	0	0.0	0	0.0	3	10.0	3	17.6	23	13.3
H. tredecimpunctata	145	55.7	33	33.3	0	0.0	0	0.0	46	26.6
Coccinula sinuatomarginata	0	0.0	0.5	0.5	0	0.0	0	0.0	0	0.0
Total, ind.	260.5 ± 61.1		99 ± 25.2		30 ± 9.2		17 ± 6.5		173 ± 38.4	

Semenov (1982) and Kuznetsov (1993) recorded the feeding of *Coccinella trifasciata* on bird cherry. *Coccinella septempunctata* L., *Propylea quatuordecim-punctata* L., and *Hippodamia tredecimpunctata* L. occur both on woody and on herbaceous vegetation. According to our data, the same three species were also dominant on winter rye crops in 1987–1990 and on spring cereals in 1987–1988 (Tables 1–3). After 1990, *H. variegata* became the prevalent species in the winter rye agrocenosis, and *P. quatuordecimpunctata*,

Table 3. Relative abundance of adults of the family Coccinellidae in the winter rye agrocenosis during the vegetation season (means, ind./100 net-sweeps)

Species	1987		1988		1989		1990		1998		1999		2000	
	ind.	%	ind.	%	ind.	%	ind.	%	ind.	%	ind.	%	ind.	%
Coccinella septempunctata	9	8.9	29.5	28.5	18	24.3	14	32.3	7	13.2	1	3.3	7	14.0
C. trifasciata	0	0.0	0.5	0.5	2	2.7	1	2.3	3	5.7	0	0.0	0	0.0
Propylea quatuordecimpunctata	17.5	17.2	22.5	21.7	18	24.3	9.5	21.8	3	5.7	3	10.0	10	20.0
Hippodamia variegata	0.5	0.5	7	6.8	8	10.8	2	4.6	23	43.4	16	53.3	26	52.0
H. arctica	0	0.0	13	12.6	6	8.1	3	6.9	7	13.2	10	33.3	7	14.0
H. tredecimpunctata	67	66.0	24	23.2	18	24.3	6	13.8	10	18.9	0	0.0	0	0.0
H. septemmaculata	1	1.0	2	1.9	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Anisosticta novemdecimpunctata	6.5	6.4	4.5	4.3	2	2.7	7	16.1	0	0.0	0	0.0	0	0.0
Coccinula sinuatomarginata	0	0.0	0.5	0.5	2	2.7	0.5	1.1	0	0.0	0	0.0	0	0.0
C. quatuordecimpustulata	0	0.0	0	0.0	0	0.0	0.5	1.1	0	0.0	0	0.0	0	0.0
Total, ind.	101.5 ± 23.1		103.5 ± 29.9		74 ± 13.2		43.5 ± 8.8		53 ± 9.1		30 ± 5.3		50 ± 8.3	

in the wheat and oat agrocenoses. In the same years, *H. tredecimpunctata*, *H. arctica*, and *P. quatuordecimpunctata* were also abundant on winter rye, and *H. tredecimpunctata*, *H. arctica*, and *H. variegata*, on spring crops. *Coccinula sinuatomarginata* has not been recorded on cereal crops since the beginning of the season of 1990. After 1991, *C. quatuordecimpustulata* was found in 2008 in the wheat stand where it reached the density of 25 ind./50 net-sweeps in some surveys. The highest abundance of larvae in the cereal fields during the study years was recorded for *Coccinella septempunctata*, *P. quatuordecimpunctata*, and *H. tredecimpunctata* (Table 4). The prevalence of certain species of Coccinellidae in different years may be caused by changes in the long-term dynamics of their population density, and also by the action of some ecological factors.

In the forest-steppe of West Siberia, lady beetles emerge after overwintering in late April and early May. First they keep close to their wintering places and then, as the air temperature grows, they colonize wild motley grass areas where they predate on small insects and also visit the flowers of coltsfoot, dandelion, and other plants to feed on nectar and pollen. After the appearance of aphid colonies, lady beetles spread over various biotopes. *Coccinella septempunctata*, *H. tredecimpunctata*, and *P. quatuordecimpunctata* permanently occur and reproduce on herbaceous vegetation in forest shelter belts near cereal fields. In the middle of June, when the density of pests on cereals is still low, these lady beetles occur in great numbers (up to 62 ind./100 net-sweeps) on perennial legumes. They live and reproduce on alfalfa, melilot, and clover during the whole vegetation season. In the last third of May, aggregations of *H. variegata* may be observed on melilot and alfalfa (up to 220 and 156 ind./100 net-sweeps, respectively), and those of *H. arctica*, on melilot (up to 20 ind./100 net-sweeps). These species probably overwinter in perennial herbaceous vegetation.

In May and June, most of the adult Coccinellidae feed on aphid colonies on bird cherry. At the end of the first and the beginning of the middle third of June lady beetles start laying eggs on the underside of leaves. Eggs, larvae, pupae, and adults of Coccinellidae were found on bird cherry during the last third of June. Most of the larvae pupate by the end of June, when emigration of aphids from bird cherry trees is completed; the emerging adult lady beetles leave the trees.

Table 4. Relative abundance of larvae of the family Coccinellidae in cereal agrocenoses during the vegetation season (means, ind./100 net-sweeps)

Year	Total number of ind.	*Coccinella septempunctata*		*Propylea quatuordecimpunctata*		*Hippodamia tredecimpunctata*		Larvae of other lady beetle species and first-instar larvae	
		ind.	%	ind.	%	ind.	%	ind.	%
Winter rye									
1987	7.5 ± 6.6	0	0.0	0.5	6.7	3.5	46.7	3.5	46.7
1988	24 ± 19.1	11.5	47.9	3	12.5	9	37.5	0.5	2.1
1990	5.5 ± 1.2	33.5	63.6	1	18.2	1	18.2	0	0.0
Spring wheat									
1987	44 ± 16.7	11	25.0	6	13.6	19	43.2	8	18.2
1988	46.5 ± 17.7	30.5	65.6	4.5	9.7	10.5	22.6	1	2.1
1992	205 ± 31.5	84	41.0	99	48.3	8	3.9	14	6.8
1993	337 ± 39.2	313	92.9	21	6.2	0	0.0	3	0.9
Oats									
1986	200.5 ± 27.2	96.5	48.1	3	1.5	87	43.4	14	7.0
1988	130.5 ± 63.6	100	76.6	6	4.6	7.5	5.7	17	13.0

In early and warm springs, lady beetles appear in the winter rye agrocenosis in late April and the first 10 days of May, and in case of a late spring, during the last two thirds of May, often even before the hatching of the grain aphid from the overwintered eggs. Spring crops are colonized by lady beetles during the first or middle third of June, when cereal shoots and aphids on them appear. The density of Coccinellidae is low during this period but grows considerably (up to 6–38 ind./100 net-sweeps) by the end of June and beginning of July. Oviposition of lady beetles on cereal crops was observed from the end of the middle third of June to the first 10 days of July. The duration of oviposition is about one month. The whole reproduction period of Coccinellidae may extend over three months and more (Zakharov, 1995). In case of a low density of aphids, oviposition is delayed or only single individuals start reproducing. Lady beetles lay eggs on the lower leaves of cereal cultivars or weeds, sometimes also on unusual objects (such as labels on plants, etc.), nearly always outside the aphid colonies. Eggs are laid in batches of 5–50.

The egg stage lasts 3–5 days under the laboratory conditions. Larvae of *Coccinella septempunctata*, *P. quatuordecimpunctata*, *H. tredecimpunctata*, *C. trifasciata*, and *Calvia quatuordecimguttata* develop in 8, 8, 9–12, 9–10, and 10–14 days, respectively. Larvae of the last, 4th instar stop feeding, attach themselves to the substrate by the tip of the abdomen, and pupate immediately or in 1–2, less often in 3 days. The pupal stage lasts 4, 4–5, 4–5, 5, and 3–5 days, respectively. The development of these species from egg to adult is completed in 16, 17, 15–17, 15–16, and 17–21 days, respectively.

In the cereal agrocenoses larvae start hatching in late June and early July. The highest density of the larvae is observed in the last two thirds of July, when 100 net-sweeps yield on average from 2.5 (at low densities of cereal aphids) to 51, in some years to 105 larvae; the abundance of adult lady beetles decreases considerably by this time. The peak abundance of lady beetle larvae coincides with that of aphids or deviates from it on average by a week to either side. Most larvae complete development by the time of crop ripening. In favorable weather, single larvae may develop on the stubble till the end of September.

Pupation begins in the middle or the last third of July. Larvae pupate on the upper side of leaves of cereal cultivars or weeds, on the stems, ears, and awns where the aphids feed. Mass pupation of Coccinellidae is observed in the last third of July and the beginning of August. The peak abundance of adults of the new generation was recorded in the middle third of August on winter rye (14–25 ind./100 net-sweeps) and from the first to the beginning of the last third of August on spring cereals (48–70 and 30–85 ind./100 net-sweeps

Table 5. The effects of the main soil treatment, level of chemical treatment, and the position of wheat in the crop rotation system on the abundance of cereal aphids and adult and larval Coccinellidae in the spring wheat agrocenosis (means, ind./10 net-sweeps)

Tillage variant	Level of chemical treatment	Cereal aphids				Coccinellidae			
		wheat after fallow		wheat as 4th crop after fallow		wheat after fallow		wheat as 4th crop after fallow	
		1992	1993	1992	1993	1992	1993	1992	1993
Plowing	1	133	55	130	69	10.0	5.5	13.0	2.9
	2	127	102	101	109	10.3	7.9	12.3	4.0
	3	283	381	272	401	27.9	15.2	10.0	5.7
Deep cultivation	1	128	28	159	56	12.9	4.2	12.2	3.7
	2	111	154	127	27	8.0	7.2	11.9	1.0
	3	299	304	262	211	29.7	14.2	19.7	5.9
Sweep cultivation	1	260	47	118	39	12.0	5.0	11.9	3.2
	2	209	95	120	45	9.3	4.5	10.0	2.5
	3	311	366	252	207	24.7	12.2	13.0	3.5
No tillage	1	231	55	107	56	22.0	6.9	10.3	4.5
	2	185	91	125	71	9.5	5.7	8.3	3.3
	3	283	317	143	205	32.9	13.9	22.0	6.0

Levels of chemical treatment: 1, no chemicals; 2, fertilizers only; 3, complete set of chemicals.

on wheat and oats, respectively). At the end of the vegetation season the density of adult lady beetles in the fields varied from 6 to 25 ind./100 net-sweeps. After crop harvesting, Coccinellidae were absent in the fields or present at low densities (1–7.5 ind./100 net-sweeps). Single beetles were recorded on cereal stubble until late September and early October.

According to the data of Kuznetsov (1973), *H. tredecimpunctata* and *P. quatuordecimpunctata* are bivoltine species. *Coccinella septempunctata* is also predominantly bivoltine but in West Siberia it produces one, and only in particularly favorable years, two generations; *H. variegata* is a polyvoltine species (Savoiskaya, 1983). According to our data, lady beetles occurring in cereal crops develop in one generation.

At the end of summer and in autumn lady beetles start to concentrate in their wintering places. Coccinellidae overwinter as adults, in forest shelter belts, shrub thickets, motley grass stripes along roads, finding shelter under fallen leaves, dry grass, soil clumps, detached tree bark, etc.

Adults and larvae of the species of Coccinellidae considered herein are polyphagous predators. Their main diet includes various species of aphids but they may also feed on psyllids, eggs and larvae of planthoppers, flies, phytophagous bugs, cereal leaf beetles and other beetles, lepidopterans, thrips, mites, etc. Feeding of *Hippodamia tredecimpunctata* on eggs and larvae of the Colorado potato beetle, and of *C. septempunctata* on larvae of *Phytonomus* weevils was recorded (Savoiskaya, 1983). In terms of voracity lady beetles are second only to larvae of syrphid flies. Among Coccinellidae, the most voracious are the 4th instar larvae of *C. septempunctata*. During development, a larva of *C. septempunctata* consumed on average 200 ± 15 adult grain aphids, that of *P. quatuordecimpunctata*, 46 ± 12, that of *H. tredecimpunctata*, 97 ± 5, that of *C. trifasciata*, 104 ± 19, and that of *Coccinula quatuordecimguttata*, 95 ± 9 aphids. Adult lady beetles are less voracious than their larvae. In particular, males of *Coccinella septempunctata*, *P. quatuordecimpunctata*, *H. tredecimpunctata*, *C. trifasciata*, and *Coccinula quatuordecimguttata* consumed 19 ± 2, 9 ± 1, 18 ± 3, 12 ± 4, and 17 ± 3 bird cherry-oat aphids a day, respectively, and females of these species consumed 28 ± 5, 11 ± 2, 18 ± 3, 11 ± 4, and 17 ± 3 aphids, respectively. Lady beetles feed most actively in the daytime, though under the laboratory conditions the rate of aphid consumption by unfed individuals was the same both by day and night. Satiated lady beetles do not consume whole aphids but only eat out the thorax.

Table 6. The influence of the main soil treatment, level of chemical treatment, and the position of wheat in the crop rotation system on the abundance of cereal aphids and adult and larval Coccinellidae in the spring wheat agrocenosis (means, ind./10 net-sweeps; MANOVA results)

Factors studied	Cereal aphids		Coccinellidae	
	1992	1993	1992	1993
Tillage variant:				
Plowing	175	187	13.9	6.7
Deep cultivation	179	130	15.7	6.0
Sweep cultivation	212	133	13.5	5.2
No tillage	179	133	17.5	6.7
$HCP_{0.5}$	62	56	6.2	1.9
Level of chemical treatment:				
No chemicals	158	51	13.0	4.5
Fertilizers only	137	87	9.9	4.5
Complete set of chemicals	263	299	22.5	9.6
$HCP_{0.5}$	49	45	3.6	1.7
Crop position:				
Wheat grown after fallow	213	166	17.4	8.5
Wheat grown as the 4th crop after fallow	160	125	12.9	3.9
$HCP_{0.5}$	53	37	3.7	1.4

The abundance of Coccinellidae in cereal agrocenoses did not depend on the main soil treatment system (Table 5): the influence of this factor was no greater than 2–5%. On average, in the variants with plowing, deep cultivation, sweep cultivation, and no tillage the density of adult and larval lady beetles varied from 13.5 to 17.5 ind./10 net-sweeps in 1992 and from 5.2 to 6.7 ind./10 net-sweeps in 1993 (Table 6).

The application of chemicals had a considerable impact (24.9–54.7%) on the abundance of adult and larval lady beetles (24.9–54.7%). Application of insecticide in 1993 led to a general decrease in the density of Coccinellidae as compared with 1992. However, the use of fertilizers and pesticides in both seasons facilitated a significant increase in the abundance of aphids and lady beetles as compared with the variants with no chemical treatment (see Table 5). On average for the experimental data, the density of lady beetles in crops with a full complex of fertilizers and pesticides was 22.5 and 9.6 ind./10 net-sweeps in 1992 and 1993, respectively, which was 2.1–2.3 times as great as their abundance in crops with fertilizers but no pesticides, and 1.7–2.1 times as great as that in crops with no chemical treatment (see Table 6). The reason for this is that application of chemicals (when insecticides are not used or used at early stages of crop development) ensures the best supply of plants with nutrients and stimulates their active growth, thus facilitating the development and reproduction of pests, including cereal aphids, and subsequently also lady beetles and other predators.

In the crops with complex application of chemicals in 1992 and in all the variants in 1993, lady beetles were more abundant on wheat grown after fallow (see Table 5). On average for the experiment, the densities of Coccinellidae on wheat grown as the 1st and the 4th crop after fallow were significantly different in both years of research. In particular, the mean density of Coccinellidae on wheat after fallow was 17.4 and 8.5 ind./10 net-sweeps in 1992 and 1993, respectively, which was 1.4–2.2 times as great as their density on wheat grown as the 4th crop after fallow (see Table 6). The influence of the position of wheat in the crop rotation on the abundance of predators was 10–24%.

There was no significant difference in the abundance of lady beetles on wheat grown after fallow, wheat following fallow, winter rye, oats, vetch-oat intercrop, rape, and barley, and also on wheat grown without crop rotation (Table 7). Lady beetles tended to prefer wheat grown after fallow and wheat grown without rotation. In two out of three years of research, lady beetles were significantly (by 2.5–3.9 times) less

Table 7. The influence of forecrops on the abundance of cereal aphids and adult and larval Coccinellidae in the spring wheat agrocenosis (means, ind./10 net-sweeps)

Forecrop	Cereal aphids			Coccinellidae		
	1998	1999	2000	1998	1999	2000
Fallow	375	115	439	4.3	2.7	13.0
Wheat after fallow	–	170	499	–	0.3	8.0
Winter rye	336	201	571	2.7	0.7	9.3
Oats	357	137	434	2.0	1.0	6.3
Vetch-oat intercrop	263	75	507	3.0	1.7	7.3
Rape	298	97	444	1.7	0.7	4.3
Barley	321	59	614	2.7	1.7	4.7
Wheat without rotation	353	37	363	4.7	1.0	11.3
$HCP_{0.5}$	153	77	227	3.7	1.9	7.2

Table 8. The abundance of cereal aphids and adult and larval Coccinellidae on different crops in rotation systems (means, ind./10 net-sweeps)

Crops	Cereal aphids			Coccinellidae		
	1998	1999	2000	1998	1999	2000
Wheat after fallow	375	115	439	4.3	2.7	13.0
Winter rye after fallow	72	42	184	2.7	2.0	4.0
Winter rye after melilot	100	20	155	3.0	1.0	3.3
Oats	438	268	1025	4.0	2.3	20.0
Vetch-oat intercrop	380	252	657	7.7	4.0	9.3
Rape*	51	28	95	3.0	1.0	2.0
Barley	29	21	226	1.0	1.3	11.3
Barley-melilot intercrop	96	22	279	2.7	1.7	11.3
Permanent alfalfa	–	–	–	35.3	47.7	19.0
$HCP_{0.5}$	244	91	203	3.2	2.2	9.8

* The aphids were not identified.

abundant on wheat grown after rape than on wheat after fallow. The lowest densities of aphids and Coccinellidae were recorded in 1999 as the result of dry and hot weather and the application of insecticide at the tillering stage. Some species (*H. tredecimpunctata*, *C. septempunctata*, and *C. trifasciata*) were not found at all in crops during that season. The abundance of lady beetles was restored in 2000. On the whole, during the studied seasons of 1998–2000 the influence of forecrop on the total abundance of Coccinellidae in the spring wheat agrocenosis varied on average from 0 to 16.9%.

In the studied crop rotation systems lady beetles were more abundant on the crops most strongly infested with aphids and providing additional food sources in the form of nectar and pollen: wheat after fallow, oats, vetch-oat intercrop, and in 2000, also barley and barley-melilot intercrop (Table 8). As compared with wheat after fallow, the total abundance of Coccinellidae was significantly lower on barley in 1998 (by 4.3 times) and on rape in 2000 (by 7.5 times). The preferred habitats of lady beetles were the fields of perennial alfalfa, where the density of adults and larvae reached on average 19–47.7 ind./10 net-sweeps, which was 1.5–17.6 times as high as that on wheat after fallow. The influence of the crop on the total abundance of Coccinellidae in the corresponding agrocenoses during the vegetation season was strong, comprising 43.6, 24.0, and 39.8% in 1998, 1999, and 2000, respectively.

Table 9. The influence of the spring wheat cultivation method on the abundance of cereal aphids and adult and larval Coccinellidae during the vegetation seasons (means, ind./50 net-sweeps)

Cultivation method	Cereal aphids			Coccinellidae		
	2005	2006	2007	2005	2006	2007
Wheat grown after fallow						
Extensive	–	357	410	–	15.5	13.3
Normal	–	472	402	–	17.2	11.7
Intensive	–	662	488	–	30.0	23.8
$HCP_{0.5}$	–	243	267	–	9.8	10.2
Wheat grown after wheat following fallow						
Extensive	647	–	587	16.2	–	6.2
Normal	722	–	385	24.5	–	20.0
Intensive	1088	–	337	35.5	–	24.5
$HCP_{0.5}$	245	–	327	14.3	–	8.7

Application of fertilizers and pesticides is an integral part of plant cultivation technology. The stable ecological situation in agrocenoses depends on the impact of these chemicals on the abundance and efficiency of entomophages.

During most of the seasons covered by our research, the faunas of pests and beneficial insects developed similarly in crops grown by extensive and normal cultivation methods (Table 9). In 2005 and 2006, the total abundance of aphids in intensively cultivated wheat fields, where plants possessed well-developed vegetative parts and ears, was 1.7–1.9 times as great as in extensively cultivated fields and 1.4–1.5 times as great as in crops with normal cultivation technology. No such difference in the pest abundance was recorded in 2007. During the seasons of 2005–2007, the total abundance of Coccinellidae in intensively cultivated wheat stands was 1.2–4 times as great as that in the variants with extensive and normal cultivation methods.

Thus, lady beetles constitute one of the prevalent and efficient groups of entomophages in the cereal agrocenoses of the forest-steppe zone of West Siberia. The most common of them are *Propylea quatuordecimpunctata*, *Hippodamia tredecimpunctata*, *Coccinella septempunctata*, *H. variegata*, and *H. arctica.* Different variants of soil treatment before sowing wheat do not affect the density of Coccinellidae. Wheat crops grown after fallow and cultivated with application of chemicals (without insecticides or with application of insecticides at early stages of crop development) are characterized by better developed stems and ears; this attracts pests and, in turn, also lady beetles and other entomophages. The preferred habitats of lady beetles are fields of perennial alfalfa. An important role in maintaining their abundance belongs to the surrounding biotopes: forest shelter belts, wild motley grasses, fields of clover, melilot, and other perennial and biennial legumes.

REFERENCES

1. *Adaptive-Landscape Agriculture Systems in Novosibirsk Province*, Ed. by Kiryushin, V.I. and Vlasenko, A.N. (Novosibirsk, 2002) [in Russian].
2. Aleeva, M.N. and Babushkina, N.G., "Entomophages of Cereal Aphids," in *Proceedings of the Siberian Institute of Agriculture and Chemicalization* (Novosibirsk, 1977), pp. 69–78 [in Russian].
3. Bokina, I.G., "Specific Bioecological Features of Cereal Aphids (Homoptera, Aphididae) in West Siberia and the Effects of Agrotechnical Methods on Them," Trudy Russkogo Entomologicheskogo Obshchestva **83** (1), 29–37 (2012).
4. *Ecology and Behaviour of the Ladybird Beetles (Coccinellidae)*, Ed. by Hodek, I., van Emden, H.F., and Honek, A. (Wiley–Blackwell, Oxford, 2012).
5. Evans, E.W., "Searching and Reproductive Behavior of Female Aphidophagous Ladybirds (Coleoptera: Coccinellidae). A Review," European Journal of Entomology **100** (1), 1–10 (2003).
6. Filatova, I.T., "Predatory Lady Beetles in the Middle Ob Basin," in *Studies of the Biological Method of Controlling Agricultural and Forest Pests: Proceedings of a Symposium, Part 2* (Nauka, Novosibirsk, 1965), pp. 135–139.
7. Klementyeva, L.B., "The Insect Fauna of Spring Wheat and Barley Crops," in *Proceedings of Omsk State Peda-*

gogical Institute, Issue 14 (Omsk, 1961), pp. 33–46 [in Russian].
8. Krotova, I.G., "Coccinellidae (Coleoptera) as Entomophages of Cereal Aphids in the Forest-Steppe of the Ob Region," Sibirskii Vestnik Selskokhozyaistvennoi Nauki **5**, 43–50 (1990).
9. Kuznetsov, V.N., *Candidate's Dissertation in Biology* (Novosibirsk, 1973).
10. Kuznetsov, V.N., *Coccinellidae (Coleoptera) of the Russian Far East: in Two Parts* (Dalnauka, Vladivostok, 1993) [in Russian].
11. Meier, N.F., "A Theoretical Foundation of the Biological Method of Controlling Insect Pests," Vestnik Zashchity Rastenii, Nos. 1–2, 143–152 (1940).
12. Michels, G.J., Elliott, N.C., Romero, R.A., Owings, D.A., and Bible, J.D., "Impact of Indigenous Coccinellids on Russian Wheat Aphids and Green Bugs (Homoptera: Aphididae) Infesting Winter Wheat in the Texas Panhandle," Southwestern Entomologist **26** (2), 97–114 (2001).
13. Mokhrin, A.A., *Candidate's Dissertation in Biology* (St. Petersburg–Pushkin, 2009).
14. Savoiskaya, G.I., "On the Study of Coccinellidae of West Siberia," Uchenye Zapiski Tomskogo Pedagogicheskogo Instituta **19** (1), 101–106 (1961).
15. Savoiskaya, G.I., *Larvae of Lady Beetles (Coleoptera, Coccinellidae) of the Fauna of the USSR* (Nauka, Leningrad, 1983) [in Russian].
16. Savoiskaya, G.I., *Lady Beetles Feeding on Aphids* (Agropromizdat, Moscow, 1991) [in Russian].
17. Semenov, P.V., "Lady Beetles as Predators of Cereal Aphids," Sibirskii Vestnik Selskokhozyaistvennoi Nauki **5**, 45–48 (1982).
18. Semyanov, V.P., "Lady Beetles in the Agrocenoses of Belarus," in *The Biological Method of Plant Protection: Abstracts of Papers of a Scientific Conference* (Minsk, 1984), pp. 69–71.
19. Telenga, N.A., *The Biological Method of Controlling Insect Pests: Predatory Lady Beetles and Their Use in the USSR* (Ukrainian SSR Academy of Sciences, Kiev, 1948) [in Russian].
20. Voronin, K.E., Shapiro, V.A., and Pukinskaya, G.A., *Biological Protection of Grain Crops from Pests* (Agropromizdat, Moscow, 1988) [in Russian].
21. Yablokov-Khnzorian, S.M., "The Life of the So-Called Lady Beetles," Priroda, No. 3, 44–49 (1970).
22. Zakharov, I.A., "The Two-Spotted Ladybird (*Adalia bipunctata* L.) as an Object of Genetic Studies," Genetika **31** (2), 149–161 (1995).