A COMPARATIVE STUDY OF THE EFFICIENCY OF THREE PREDATORY INSECTS *COCCINELLA SEPTEMPUNCTATA* L. [*COLEOPTERA, COCCINELLIDAE*], *CHRYSOPA CARNEA* St. [*NEUROPTERA, CHRYSOPIDAE*] AND *SYRPHUS RIBESII* L. [*DIPTERA, SYRPHIDAE*] AT TWO DIFFERENT TEMPERATURES

BY

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Introduction

Since only a few pest insects are of foreign origin in Europe, the utilization of native insects is one of the characteristics of biological control work in this continent (Franz, 1961). In Norway, little has been done in this field of research. Many of the insects have their northern limits in this country, and we should probably expect the beneficial insects to be even more sensitive to the colder climate than the pest insects are. Counts in the field, however, show parasitic as well as predatory insects to be quite numerous in several places. This at least indicates that the insects are able to live and to reproduce in our climate. We know, however, very little about how efficient our beneficial insects are.

The predators used in these experiments are *Coccinella septempunctata* L., *Chrysopa carnea* Stephens and *Syrphus ribesii* L. The prey used is the aphid *Myzus persicae* (Sulzer) reared on *Brassica napus napobrassica* (L.) Rchb. These three predators are reported as common aphid predators for other countries (e. g. Harpaz, 1955 and Gyrisco, 1958). The present experiments try to determine how efficient these predators are as aphid feeders at two different temperatures.

Material and Methods

The experiments have been carried out in the laboratory at temperatures $21^{o} \pm 1$ °C and $16^{o} \pm 1$ °C. To secure sufficient humidity, the bottom of the glass jars and the petri dishes was covered with filter paper which was moistened once a day.

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The oviposition experiments were carried out in small glass jars covered with cloth gauze. During the reproductive period, one pair of insects was kept in each jar. In order to secure complete egg records of *Coccinella*, it was necessary to count and remove the eggs three times each day, because of the strong tendency of the females to devour their own eggs, even though an adequate supply of food was present all times (CLAUSEN, 1916). For the other species the eggs were removed once a day.

The adults of *Coccinella* were fed with aphids and honey, the two other species with honey and pollen. The flowers used were: *Anemone nemorosa* L., *Chrysanthemum leucanthemum* L., *Matricaria inodora* L. and *Taraxacum* sp. The insects were observed several times to feed on these flowers.

The eggs were isolated, and the larvae put in petri dishes soon after hatching, one in each dish. The number of aphids consumed was checked and renewed at the same time every day.

The material was put out in the field for hibernation in the middle of October, and was taken back to the laboratory again in April. The examinations were carried out during 1962, 1963 and 1964.

Biological characteristics of the species

Coccinella septempunctata L.

C. septempunctata is among the most numerous coccinellid beetles found in Norway. The ladybirds hibernate in the adult stage, and move from hibernating quarters in April or early May, depending upon the spring. Hardly any aphids are seen in the field at that time. The bulk probably enters the hibernation quarters in September, but beetles have been seen in the field in October.

The oviposition period has varied during the laboratory investigations between 3 days and 15 1/2 weeks. The last figure refers to eggs collected from the same female from the beginning of May till the middle of September. The average number of eggs is seen in table 1. The highest number found is 1,005.

The hatching per cent is rather low. As found earlier (BANKS, 1956), larvae may feed on infertile eggs or eggs still unhatched, before leaving the egg shell. (In these experiments: 36 larvae out of 40 eggs, 18 out of 39). The egg feeding does not seem to be necessary for the larvae, but the fed larvae benefit by living longer, and are able to make a more prolonged search for aphids. In the case of low aphid population density, however, cannibalism represents a survival value for some larvae.

The developmental period is seen in tables 1 and 2. According to HODEK (1958) the photoperiod is very important for the speed of development of *C. septempunctata*. Continuous light has the same effect as 12 hours of light a day. Continuous darkness retards the

TABLE 1

Biological characteristics of *Coccinella septempunctata*, *Chrysopa carnea* and *Syrphus ribesii* (1)

CHARACTERISTIC	*C. septempunctata*	*C. carnea*	*S. ribesii*
Average total egg per female (2)	814	477	143
Hatching percent (3)	44.7	84.3	67.2
Developmental period (days) (4)	28.5	35.1	24
Egg stage (days)	5	5.6	2.6
Larval stage (days)	15	14.6	11.6
Pupal stage (days)	8.5	14.9	9.9
Number of generations a year	1	2	2
Oviposition period (days)	65	35	17
Theoretical number of progeny produced during one summer, from one female (5)	309	52636	3763

(1) 21° ± 1 °C.
(2) Figures for each species based on egg number from 14 females. One female and one male were kept in each glass jar.
(3) Figures based on 2,000 eggs from *S. ribesii*, and 7,000 eggs from the two other species.
(4) Figures refer to 67 replicates for *C. septempunctata*, 77 for *C. carnea* and 53 for *S. ribesii*.
(5) Based on egg number, hatching percent, number of generations a year and the survival rate found in the material. Sex ratio 50 %.

speed of development about 15 per cent. The larvae in Tables 1 and 2 are reared at natural day length for this country during summer, i. e. more than 12 hours of light a day. Larvae reared at constant light were also found to have the same speed of development. This indicates the normal photoperiod in this country to be long enough to induce the most rapid development.

The survival rates at the different temperatures vary to some extent. At 21 °C, 28 imagines emerged out of 33 larvae (85 %). At 16 °C, 25 imagines emerged out of 39 (64 %). If the larvae and pupae are kept at 21 °C and 16 °C alternately, hardly any failure in development has been found.

In accordance with the duration of the development, we should expect this species to have two generations a year. Field observations show egg batches during the whole summer, the highest number of larvae and imagines is seen in July and August.

During the laboratory experiments the progeny of the hibernated females do not oviposit till next summer, even if they emerge as early as June 10th. It is possible to break this diapause, but the factors that prevent the breaking are not clear yet. Photoperiod and food are mentioned as important factors for other beetles (DE WILDE & *al.* 1959). This problem will be treated in a following paper. The hibernated females, as mentioned before, have an oviposition period of several weeks, and all the eggs and larvae in the field during the whole summer must originate from the hibernated imagines. According to HAGEN (1962), *C. septempunctata* has one generation a year in Germany and England. We may also add Norway to the one generation area.

Consequently, the life time of this beetle should be about one year, and this seems to be the rule. One female, however, has been found to hibernate twice during this investigation. This female, collected in the field in May 1963, had a very short oviposition period that summer, 16 days only, with an egg number of 126. In October it was put out in the field, and taken back to the laboratory again in April. This year the female placed 534 eggs, within a period of 6 weeks. The female died in the middle of July.

Chrysopa carnea STEPHENS (= *vulgaris* SCHNEIDER)

Several species of *Chrysopa* are known from this country, among the most numerous is *C. carnea*. This lacewing hibernates in the adult stage, and may be seen indoors during the winter. The imago is seen in the field again in June. The highest population of imagines is found in the field in August to September. During the laboratory investigation, the imagines were put out for hibernation in October.

Other authors (DEBACH & *al.* 1964) mention *C. carnea* as a liquid feeder. During the present investigation, the imagines have been fed on honey and pollen. No eggs were obtained in experiments where the females had access to aphids only.

The biology of this species has recently been treated by NEUMARK (1952). The biological characteristics found during this investigation are seen in Tables 1 and 2. The oviposition period may vary between 20 and 80 days. The highest number of eggs per female in the present material is 1.022. The number of eggs a day per female varies considerably, the highest number counted is 57, the average 13.6 eggs. Very often the female oviposits every day.

The newly hatched larvae may suck out the other eggs, as found by BÄNSCH (1964). This cannibalism has the same effect as mentioned for *Coccinella*. The survival rate during the laboratory experiments has varied. If the progeny is kept at 21 °C, 97 % will emerge. At 16 °C the survival rate has been 79 %. If kept for 8 hours at 21 °C and 16 hours at 16 °C, 30 emerged out of 35 larvae (survival rate 85.7 %), at the opposite conditions the corresponding figure is 94.5 %.

TABLE 2

Comparison of developmental period and theoretical number of aphids consumed of the three predators at different temperatures.

	Coccinella septempunctata			
	21 °C	16 °C	21 °C — 8 h 16 °C — 16 h	21 °C — 16 h 16 °C — 8 h
1. Developmental period (days) (1)	28.5	60.4	45	32.5
2. Larval stage (days)	15	35	24.6	16.5
3. Number of aphids consumed per larva	420	399	413	425
4. Theoretical number of aphids consumed of the larvae produced during one summer	129,780			
5. Number of aphids consumed of the imagines during one summer	270,349			

(1) Except the 21 °C figures, the number of days for each temperature are based on 30 replicates.

It has been difficult to follow the generations in the field, but the laboratory investigations indicate *C. carnea* to have two generations a year in Norway. The species hibernates as imago, and in the laboratory the progeny emerges during the first days of July. The preoviposition period is about one week. At a temperature of 21 °C, the second generation emerges in the middle of August. In the field we must calculate on two obligate generations each summer.

Syrphus ribesii L.

Several species of *Syrphidae* are found in this country, one of the most numerous is *Syrphus ribesii*. According to ESSIG (1942), it is a species of Europe and North America. COE (1953) mentions it as a common species in England.

BHATIA (1939) mentions species of *Syrphus* to hibernate either as larvae or as pupae according to the stage they may be in at the onset of winter. The species concerned in this investigation hibernates in the larval stage, as fully grown larvae. The larvae drop to the ground together with leaves in the fall, and are found there in early spring. Pupation takes place during the first days of May. The imagines, as mentioned above, feed upon nectar and pollen.

The oviposition period has varied between 9 and 40 days, during the laboratory investigations. The preoviposition period lasts for about a week. The highest number of eggs found is 366, the lowest 60. The number of eggs a day may reach as high as 138. The larva is described in more details by HEISS (1938) and BHATIA (1939).

The survival rate during the development is very high. If the progeny is kept at 21 °C, 40 imagines emerged out of 45 larvae (89 %), at 16 °C only 2 larvae out of 33 failed to develop (94 %). If kept for 8 hours at 21 °C, and 16 hours at 16 °C, 25 imagines emerged out of 31 larvae, at 16 hours at 21 °C and 8 hours at 16 °C the corresponding figure is 30 imagines out of 35 larvae.

TABLE 2

(continued)

	Crysopa carnea				*Syrphus ribesii*			
	21 °C	16 °C	21 °C — 8 h 16 °C — 16 h	21 °C — 16 h 16 °C — 8 h	21 °C	16 °C	21 °C — 8 h 16 °C — 16 h	21 °C — 16 h 16 °C — 8 h
1.	35.1	69	54	41	24	37.5	32.5	26.5
2.	14.6	28	22	16	11.6	15	14.6	12
3.	393	298	324	317	562	609	736	624
4.	20,839,218				2,162,576			

According to DIXON (1959) and BOMBOSCH (1962) the odour of the aphid stimulates oviposition by *S. luniger* MEIG. and *S. corollae* FABR. The present investigation suggests the same to be true for *S. ribesii*. No eggs have been laid during the laboratory experiments till plants with aphids were present. In the field eggs are always found near aphid colonies.

S. ribesii has two generations a year in Norway. The fly hibernates as mentioned as larva, and enters the pupal stage in spring. Imagines are found at the end of May, and eggs and larvae are seen shortly afterwards. Unfortunately, it has been impossible to follow the fly and its progeny during the whole summer, since the females emerged in the laboratory produce infertile eggs only. These experimental difficulties are reported by other authors (SCHNEIDER, 1948; BOMBOSCH, 1957). Females collected in the field in August, however, readily lay eggs, and the progeny of these females in the field enters the hibernation stage.

Comparison of the three species

The efficiency of predatory insects will depend partly on their surrounding factors, partly on their biology, their prey consuming and searching capacity. These qualifications may again be a compound of different components, the significance of which may vary in different areas.

As to the three species concerned, their biology and prey consuming capacity vary to some extent. *C. septempunctata* consumes fewer aphids at the higher than at the lower temperature. For *C. carnea* the highest number of aphids is found at 21 °C, the lowest at 16 °C, the larvae seem to be able to consume a higher number of aphids if the temperature rises. As to *S. ribesii*, the lowest number is found at 21 °C. This species seems to be able to consume more aphids at lower and variable than at higher temperatures. At 21 °C *C. carnea* is the species with the highest theoretical number of aphids consumed during one summer.

But the species' efficiency in the field depends on different qualifications.

The possibility for newly hatched larvae to find the host, depends to some extent on where the eggs are placed, the activity of the larvae, and how long the larvae are able to survive if no food is available. Some differences are found for the three species as to their oviposition behaviour. In the field, the egg batches of *C. septempunctata* are usually found on leaves not very far from aphid colonies. The presence of aphids does not seem necessary, but the laboratory experiments indicate the egg number to increase with high aphid population density.

C. carnea place their eggs without the presence of aphids, they have been kept in glass jars with flowers and honey only. In the field, the eggs are found scattered on leaves, with high or low aphid density. As to *S. ribesii*, this species seems to need aphids as stimulation for the oviposition. According to BOMBOSCH (1962) *S. corollae* is able to keep the eggs back if no aphids are present. The same is found for *S. ribesii*. Isolated females oviposit as soon as leaves with aphids are put into the glass jar. The eggs are placed separately.

S. ribesii is the species where the female shows the strongest attraction to the aphids. On the other hand, the larvae of the other species are more active, and have the possibility to move faster. According to FLESCHNER (1950), *Chrysopa californica* COQ. is able to move with a speed of 22.9 feet (= 68 m) per hour (80 °F = 27 °C). The speed of *C. carnea* larva has not been determined, but is probably the same. According to oviposition behaviour and activity of the larvae, all three species are regarded equally capable of aphid discovering.

Table 3 shows the life time of newly emerged larvae if no food is available. As to *C. septempunctata* the larvae for this experiment were removed from the egg batch before having eaten any eggs. The table shows the three species to live about the same time if kept with access to water only. If honey is available their life time increases, especially for *C. carnea*. Their survival value at low host population density will, however, to some extent depend on their ability to live on other food. In the field, larvae of the species concerned are found on different trees and bushes with different species of aphids. Feeding tests in the laboratory are consistent with these observations. But the larvae are able to survive on other food too, including eggs of other insects. In the laboratory, larvae of *C. septempunctata* have developed on eggs from *Ephestia kühniella* ZELLER. The number of eggs eaten per larvae averaged 1.156. The larva of *C. carnea* very readily attacks different species of thrips.

TABLE 3

How long newly emerged larvae may live without food (days)

(température : 21 ± 1 °C; figures for each species based on 20 replicates)

SPECIES	WATER ONLY		WATER AND HONEY	
C. septempunctata	3.0	max. 4 min. 2	9.6	max. 15 min. 1
C. carnea	3.8	max. 9 min. 2	24.3	max. 45 min. 3
S. ribesii	3.0	max. 7 min. 1	4.2	max. 8 min. 1

As to the insects' efficiency in the field, their searching ability is thought to be of great importance. This qualification is very difficult to determine in the laboratory. Their searching ability will, however, to some extent depend on their activity and the time used to consume the required food. The time used for eating during the different larval stages is seen in Table 4. According to this *C. carnea* is the species which uses the shortest time to consume the necessary amount of aphids, while the corresponding figure for *S. ribesii* is 4 to 5 times higher. Comparing this with the larval mobility, *C. carnea* will be able to cover a larger part of the host plant each day than is the case for *S. ribesii*. This will be of some value at least at low aphid density.

TABLE 4

Time taken by predators to consume aphids

(Figures for each species based on 70 replicates)

CHARACTERISTIC	*C. septempunctata*	*C. carnea*	*S. ribesii*
—	—	—	—
1. larval stage — one aphid	42.1 mn	16.6 mn	85.3 mn
2. — —	15.4 mn	4.8 mn	11.5 mn
3. — —	4.8 mn	1.5 mn	4.5 mn
4. — —	2.1 mn		
Time for eating per day 1. l. st.	2.5 h	1.7 h	6 h
— — 2. —	3.7 h	1 h	
— — 3. —	1.3 h	1.5 h	
— — 4. —	1.6 h		

The possibility of the predators to subsist at low aphid population depends also on the amount of food necessary to reach a fully grown larval stage. Experiments show that seven aphids a day during the whole larval period enable complete development. This was the case with *C. septempunctata* and *C. carnea*. The average number of aphids consumed per larva was for *C. septempuntata* 133.8 and for *C. carnea* 72.3. All the larvae of the latter species reached the pupal stage and only 4 out of 25 did not emerge. As to *C. septempunctata* most of the larvae reached the pupal stage, while only 3 out of 8 emerged.

The specimen reared on this amount of food were, however, smaller than the others, and produced less eggs. But the experiments at least show the development to occur on an amount of food, far below the maximum number of aphids that can be consumed. One might have expected less food to prolong the developing period. This is not the case when aphids are used.

According to the experiments with varied temperatures, several insects are found to develop faster if the temperature is varied as compared to the contant one. This does not seem to be the case for the species dealt with here.

At 21 °C *C. carnea* seems to rate highest in all qualifications determined for aphid controlling ability. But the predators have to be well adapted to a broad range of climatic conditions (DEBACH & *al.*, 1964). This is even more necessary for predators at the northern latitude. In the field area of Norway where this investigation has been carried out, the mean temperature for June and July is lower than 16 °C. (Meteorologic data for Ås 1962-65.) All three species are able to develop at this temperature (Tab. 2), but the survival rate is different for the three species. *S. ribesii* is the species with the highest survival rate at 16 °C, and the species where the speed of development is retarded with only a few days at 16 °C as compared to 21 °C. *S. ribesii* seems to be the species most adaptable to the lowest temperature used, and the most promising species at our latitude. But the efficiency of all these species has to be studied more thoroughly in the field before any conclusion can be drawn.

ZUSAMMENFASSUNG

Die drei Arten *Syrphus ribesii*, *Chrysopa carnea* und *Coccinella septempunctata* leben im Larvenstadium bekanntlich alle von Blattläusen. Aufgabe der vorliegenden Untersuchung ist die Bestimmung, inwieweit diese Arten als regulierende Faktoren hinsichtlich des Auftretens von schädlischen Insekten unter unseren Klimaverhältnissen wirksam werden. Laborversuche brachten Klarheit über die Biologie dieser Lebewesen : *C. septempunctata* hat eine Generation im Jahr, *C. carnea* zwei Generationen im Jahr, und *S. ribesii* zwei Generationen im Jahr. Die Zahl der je Larve vertilgten Blattläuse belief sich für *C. septempunctata* auf 420, für *C. carnea* auf 393 und für *S. ribesii* auf 562 Stück. Die erstgenannte Art verzehrte etwa die gleiche Anzahl Blattläuse unter allen untersuchten Temperaturverhältnissen, *C. carnea* hatte den höchsten Verzehr bei hohen Temperaturen, während es den Anschein hat, dass *S. ribesii* bei wechselnden Temperaturen am wirkungsvollsten ist.

Da *C. carnea* die grösste Nachkommenzahl innerhalb eines Sommers hat, wird diese Art auch die meisten Läuse während eines Sommers vertilgen. Die Zahl der verzehrten Blattläuse wurde für diese Art auf 20 839 218 berechnet. Die Nachkommen von *C. septempunctata* werden erwartungsgemäss 129 780 Blattläuse und die von *S. ribesii* 2 162 576 Blattläuse vertilgen.

In Bezug auf die Möglichkeit, Blattläuse zu finden, scheint es zwischen den untersuchten Arten keine besonderen Unterschiede zu geben. Die Eiablage erfolgt auf etwas unterschiedliche Weise; zieht man jedoch die Beweglichkeit der Larven in Betracht, dann stehen diese drei Arten ziemlich gleich begünstigt da. Die neugeschlüpften Larven von *C. carnea* können länger ohne Nahrung auskommen als die der anderen Arten, und benötigen je Tag eine kürzere Zeit zum Fressen. Diese Art ist den anderen weit überlegen im Falle von hohen Temperaturen. Bei niederen Temperaturen hingegen ist die Sterberate für *S. ribesii* am geringsten. Dieses dürfte darauf hindeuten, dass *S. ribesii* für unsere klimatischen Verhältnisse am geeignetsten ist. Es bedarf jedoch einer näheren Untersuchung der Reaktion der einzelnen Arten unter Feldbedingungen, bevor endgültige Schlüsse gezogen werden können.

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