Ground Beetles (Coleoptera: Carabidae): Their Potential as Bio-agents in Agroecosystems

12

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Abstract

The first step in any integrated pest management (IPM) system is a complete study of the agroecosystem. In biological agriculture, pest control depends largely on the activities of the natural enemies in the field habitat and on the use of various agricultural techniques. Technological advances have allowed productivity to increase, but not without consequences on the sustainability of the agroecosystem. In this chapter, we provided a brief account of the distribution and diversity by two case studies, prey record and biosafety of synthetic insecticides against carabids or ground beetles.

Keywords

Carabids or ground beetles • Distribution • Prey records • Mass production

12.1 Introduction

Simplification of the crop ecosystem often results in decreased predation pressure, which may cause pest outbreaks (Dempster and Coaker 1974; Potts 1977). Interaction between insects and plants is strongly influenced by the higher trophic levels, which include the predators and parasites. Augmentation of natural enemies, mass rearing and release at appropriate stage and condition are major components in IPM. Successful culturing of suitable prey in the laboratory or rearing predators and parasitoids depends on the biology, behaviour and reproductive fitness of natural enemies. In order to augment this approach in biological control, increased attention needs to be diverted towards factors involved in successful predation, prey suitability as well as survivorship. Duration of the postembryonic development, fecundity, longevity and number of prey consumed during the lifetime are of paramount importance in assessing the predatory efficiency of an individual (Ananthakrishnan 1996). The quality and quantity of nutrients of the prey influence the growth rate and survival of the predator (Ambrose and Subbarasu 1988; Ambrose et al. 1990; O'Neil and Wiedenmann 1990; Ambrose and Rani 1991). The fecundity and life table

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characteristics, such as generation time as well as intrinsic rate of population increase (Awadallah et al. 1986), are also affected.

Generalist predators (vertebrate and invertebrate arthropod groups) are usually abundant in natural agricultural systems; however, they have more often been thought to be poor biocontrol agents. This prediction is based largely on theoretical considerations that generalist predators lack prey specificity, often have longer generation times than pests (Riechert and Lockley 1984) and interfere with other predators in addition to preying upon herbivorous pests (Polis and Holt 1992); besides, the high frequency of interference among predators, coupled with their often long development times, makes mass rearing of generalist predators economically unfeasible (DeBach and Rosen 1991). Therefore, much research has focused on identifying and manipulating characteristics of surrounding habitats to provide source populations of predators to migrate into agricultural fields (Best et al. 1981; Gravesen and Toft 1987; Nentwig 1988; Luff and Rushton 1989; Mangan and Byers 1989; Heidger and Nentwig 1989; Hance et al. 1990; Bedford and Usher 1994; Kajak and Lukasiewicz 1994; Barbosa 1998).

With a view to determine the extent to which interference among generalist predators limits their effectiveness as biocontrol agents, Snyder and Wise (1999) manipulated immigration of a guild of actively hunting generalist ground predators, carabid beetles and lycosid spiders, by intercepting them as they attempted to enter fenced 50-square-metre vegetable gardens. Immigration was blocked, allowed at the mean rate measured at the field site, or doubled. Altered immigration rates were maintained through a spring garden of cabbage, bean, eggplant and cucumber, followed by a summer garden of squash. Densities of carabids and lycosids were monitored to discover if altering their immigration rate changed their densities in the plots. Similarly, densities of other predators on the ground and in plant foliage, pest numbers and vegetable yields were monitored. Doubling the immigration rate of carabids and lycosids approximately doubled the densities of carabids inside the plots, but did not increase lycosid densities. Increasing the rate of immigration of carabids and lycosids depressed densities of non-lycosid ground spiders. In the spring gardens, manipulation of carabid and lycosid immigration did not influence numbers of predators or herbivores in the foliage and did not affect vegetable productivity. In contrast, in the summer gardens, foliage-dwelling predators were lower, pest densities were marginally lower, and squash productivity was higher in the carabid and lycosid immigration plots compared to the no-immigration treatment. Doubling carabid and lycosid immigration rate never increased the magnitude of their effects on other predators, pests or plant productivity. Predator interference limited lycosid establishment, reduced densities of other predator taxa and apparently prevented a doubling of carabid densities from having an increased impact on pest numbers. Nevertheless, despite widespread effects of predator interference, allowing immigration of lycosids and carabids increased squash productivity.

Despite theoretical misgivings, increasing evidence indicates that generalist predators can reduce pest populations in agroecosystems (Riechert and Lockley 1984; Chiverton 1986; Nyffeler and Benz 1988; Young and Edwards 1990; Wise 1993; Rosenheim et al. 1993; Nyffeler et al. 1994a, b; Lang 1997). The challenge is to reconcile the theoretical limitations of generalist predators as biocontrol agents with their reported effectiveness in some agroecosystems. The potential complexity of inter-predator interactions makes it difficult to answer these questions without conducting large-scale field experiments (Rosenheim et al. 1995).

12.2 Carabids: An Introduction

Carabids or ground beetles, as they are commonly known, are species rich and abundant in arable sites, but are affected by intensive agricultural cultivation. Carabids are negatively affected by deep ploughing, while enhanced by reduced tillage systems. No negative effects have been found for mechanical weed control and even flaming. Proper organic fertilization and green manure application enhance carabid recruitment (Porhajasova et al. 2012). Intensive nitrogen amendment might indirectly affect carabids by altering crop density and microclimate. They are enhanced by crop diversification in terms of monocrop heterogeneity and weediness as well as by intercropping and the presence of field boundaries or farmscaping, although corresponding increases in their pest reduction efficacy have not yet been evidenced.

The role of arthropod predators, the carabids in particular, in natural pest control of cultivated crops has become increasingly clear. The ground beetles (Carabidae) are of great importance in the bio-regulation of insect pests, but their significance has not been assessed precisely. Most members of the family Carabidae are primarily carnivorous; larvae as well as adults are nocturnal and, hence, less well known. As early as 1883, Forbes reported aphids to be a component of the carabid diet, which was confirmed by Skurhavy (1958). The beetles exhibit polyphagy of diverse order (Davies 1953, 1959; Thiele 1977). Scherney (1959) indicated the possibility of carabid beetles being used in the biological control of crop pests and the idea that, they potentially reduce some pest populations, was corroborated by Coaker (1966). However, estimates of the effective diminution of the prey species vary considerably. Dunning et al. (1975) could not demonstrate any real effect of the different carabid numbers on aphid populations, but the results suggest that aphid numbers and virus incidence were being influenced by carabids. There has been increasing attention to carabids as predators of aphids (Hengeveld 1980; Hance 1987; Sunderland et al. 1987; Chiverton 1986, 1987; Helenius, 1990). The value of ground beetles to manage red cutworms (Frank 1971) and the black cutworm, *Agrotis ipsilon*, is also reported. The adult *Pterostichus melanarius* (Ill.) has been recorded to consume aphids, carrot weevil, bean weevil and codling moth in the field. In laboratory studies, *P. melanarius* can consume about 12 onion fly pupae a day. This species is very common, sometimes the most abundant, in some agricultural fields (Lys and Nentwig 1992). Many species breed in crop fields, and the fields can be a source of recruitment to the local populations. In Scandinavia, *Bembidion lampros* (Herbst) is abundant, univoltine adult overwintering species breeding in annual crops such as cereals (Wallin 1989).

12.3 Diversity and Distribution

Studies on the diversity and abundance of carabids in arable lands from the temperate and subtemperate zones have been well documented: 39 species of carabids were recorded from soybean with higher density and species diversity in June (Ferguson and Mc Pherson 1985), 45 species from pea (Novikov 1984), 29 species from sugar beet (Purvis and Curry 1984), 82 species from various field crops and crop rotations from the Poltava region of the former USSR (Brunner and Kolesnikov 1983), 54 species from cabbage fields (Hokkanen and Holopainen 1986), 26 species from a maize monocrop (Lövei 1982), 26 species from different field crops in Michigan (Dunn 1982) and 52 species belonging to 21 genera from the rotational intensive cropping systems of central non-chernozems in Russia. The dominant species being *Poecilus cupreus* Linnaeus forming 60.3 and 65.7 % of the total catch during 1991 and 1992, respectively (Swaminathan 1992; Isaichev and Swaminathan 1993).

In India, work on carabid faunal complex for forest ecosystems and of the Indian subcontinent is reported (Andrews 1929); however, work on carabids as bio-agents in pest management has been scanty. Rajagopal and Kumar (1988) have studied the predation potential of *Chlaenius panagaeoides* (Laferte) (Coleoptera: Carabidae) on cowpea aphid *Aphis craccivora* Koch (Homoptera: Aphididae). Rajagopal et al. (1992) have described the reproductive behaviour of certain carabid species. Vennila and Rajagopal (1999) have suggested the use of either 25 or 35 pitfall traps as optimum for assessing carabid diversity for the precise estimate of carabid species distribution. A diverse

Table 12.1 Light trap catches of two dominant carabid genera during *kharif* 1998

Observation week (1998)	Adult beetle genera (Numbers per week) *Casnoidea*	*Chlaenius*	Atm. temp. (°C) Max.	Min.	Rel. humidity (%) Morn.	Even	Total rainfall (mm)
06–12/08	14	06	29.8	24.5	94	83	87.6
13–19/08	00	00	30.4	23.7	86	75	0
20–26/08	06	02	32.2	23.0	91	63	48.4
27/08–02/09	05	04	30.5	23.4	89	69	31.3
03–09/09	01	00	31.8	22.3	88	65	63.9
17–23/09	88	22	28.6	22.5	96	84	89.2
24–30/09	03	05	31.4	21.8	93	67	44.9
Corr. coeff. **r** – values for *Casnoidea*			- 0.41	−0.29	+0.39	+0.37	+0.66
Corr. coeff. **r** – values for *Chlaenius*			- 0.66	−0.23	+0.63	+0.59	+0.77

Note: *Crops associated in sampled area – green gram, black gram and soybean*

fauna of 14 carabid species belonging to 11 genera were collected during March through October 1998 (Table 12.1), of which two species were predominant: *Casnoidea indica* Thunberg and *Chlaenius viridis* Chaudoir. Adults of *C. indica* exhibited preference for the cotton aphid, consuming 250 aphids per day. Larvae of *C. viridis* were observed to prey upon the soybean leaf webber, *Lamprosema* sp. in the field, while under laboratory conditions, a single adult could consume 9-tobacco caterpillar (*Spodoptera litura* (F.)) larvae per day. An equal liking for the larvae of cotton leaf roller (*Sylepta derogata*) as prey was also observed (Swaminathan et al. 2001). Vennila and Rajagopal (2003) have classified the life cycles of 18 carabid species based on their phenology indicating 10 species as monsoon breeders having overlapping generations with adult gonad dormancy during winter and summer.

12.4 Conserving and Manipulating Carabids in Agroecosystems

It has become increasingly clear that ground beetles are important polyphagous natural enemies in agricultural landscapes that have the potential to suppress major insect pest species from reaching outbreak levels. Moreover, if augmented through their conservation, they will restrict minor insect pest species from becoming major ones. Many studies have analysed the importance of habitat characteristics, management practices and crop type on the conservation of carabid communities. As a general rule, while common agricultural practices such as pesticide applications and tillage frequently reduce carabid beetle abundance, organic and low-input production systems usually sustain more abundant beetle communities than conventional systems.

12.5 Ground Beetles' Association in Agroecosystem

The major factors conditioning the associations of ground beetles in agroecosystems are:

(a) The temporal stability of the habitat – with stable habitats providing suitable and sustainable environment.
(b) The type of tillage applied to the annual crop – lower input and reduced tillage enhance carabid diversity and abundance. Organic or biologically managed farms are more suited for Carabidae conservation.
(c) The type of crop – early crops and crops with greater cover favour carabid beetle abundance.
(d) Crop diversification through intercropping/multiple cropping, farmscaping and mulching positively affect the population build-up.

(e) Beetle activity is known to be correlated with hunger levels and availability of preferred prey.
(f) The soil hydrological regime, atmospheric humidity and temperature affect carabid diversity and numerical abundance.

12.6 Abundance of Predatory Carabids in Agroecosystems

Prior to taking up steps to conserve and augment these bio-agents in agroecosystems, extensive surveys to evaluate the diversity and abundance of predatory carabids in different crop ecosystems shall become necessary to identify the dominant species that can be conserved for the future. Besides, the surveys shall also enable one to know about the resident species. Studies on their biology must also be taken up for proper utilization of the species concerned as a bio-agent. Low-input farming with reduced tillage or otherwise biologically managing the farms shall become a prerequisite to enhance the predatory activity of these beneficial arthropods. Diversified cropping should be followed with good ground cover to harbour carabid beetles and their grubs for diurnal activity. Use of synthetic pesticides has to be avoided to safeguard these natural enemies.

The soil hydrological regime, soil treatment and crop cultivation determine the carabid population structure. The dominance structure and seasonal population dynamics of carabids vary according to the crop type and density or ground cover. Although the carabid beetles are well known to naturalists, there are only few papers on their food requirements. Hengeveld (1980) has reviewed the qualitative and quantitative aspects of the food of ground beetles. Efforts are therefore required to conserve and augment these non-specific epigeic predators, especially the carabid beetles to suitably fit in diversified agroecosystems based on IPM technology.

In its natural form, farmers who practice organic and other sustainable growing methods have used Bt formulations since the 1950s as a spray to kill pests without damaging beneficial and non-target insects or other wildlife. However, both the Cry1Ab and Cry1F Bt toxins produced by GM insect-resistant maize are significantly different: they are a shorter, or truncated, form of the protein. This truncated (or shortened) form is less selective than Bt sprays and therefore has potential to harm non-target insects in addition to the pests for which it is intended.

The possible effects of GM crops on entomophagous arthropods is a major concern, since these organisms play an important role in natural pest regulation and may affect the development of resistance towards the transgene product in the target pest. Thus, a good level of compatibility between GM-based strategies with biological control is necessary for a sustainable deployment of a GM crop (i.e. within an IPM framework).

Investigations on the effects of transgenic maize (*Zea mays*) expressing *Bacillus thuringiensis* toxin (Bt maize) on larval and adult *Poecilus cupreus* carabid beetles in laboratory studies showed that under no-choice trials, neonate *P. cupreus* larvae fed exclusively with *Spodoptera littoralis* caterpillars, which had been raised on Bt maize, and the mortality of carabids increased up to 100 % within 40 days. The experiment was repeated with 10-day-old beetle larvae, and Bt treatment resulted in fewer pupae than in both controls and in a higher mortality than in the *Calliphora* control. *Spodoptera littoralis* was suitable as exclusive prey in no-choice tests, at least for 40 days, although prey quality seemed to be low compared to *Calliphora* pupae. The observed effects are most likely indirect effects due to further reduced nutritional prey quality. However, direct effects cannot be excluded. In the second part of this chapter, exposure of *P. cupreus* to Bt-intoxicated prey was examined in paired-choice tests. Adult beetles were offered a choice between different prey conditions (frozen and thawed, freshly killed or living), prey types (*S. littoralis* caterpillars, *Calliphora* sp. pupae, cereal aphids) and prey treatments (raised on Bt or conventional maize). Living prey was preferred to frozen and dead prey. Caterpillars were only preferred to fly

Table 12.2 Distribution of carabids in rotational intensive cropping systems, 1990

Rotational cropping systems	Population abundance of carabid species (%)						Shannon diversity index
	Poecilus cupreus	*Poecilus versicolor*	*Pterostichus melanarius*	*Harpalus affinis*	*Pseudophonus rufipes*	Other species	
Winter wheat	59.17	12.68	15.01	1.89	2.52	8.73	1.2377
Perennial clover II year	75.14	17.20	0	2.40	1.00	4.26	0.7875
Rye + *Vicia faba*	74.12	12.00	1.25	7.45	0	5.18	0.8780
Perennial clover I year	47.75	10.09	12.61	5.63	4.95	18.97	**1.4716**
Winter wheat	61.44	13.02	7.60	1.50	3.00	13.44	1.1985
Barley + clover	58.7	12.46	9.56	3.72	4.24	11.32	1.2997
Oats	37.32	17.94	12.68	10.00	6.21	15.85	**1.6327**

pupae and aphids when living. Prey treatment seemed to be least important for prey selection. The tests showed that *P. cupreus* ingested caterpillars readily and there was no evidence of them avoiding Bt-containing prey, which means exposure in the field could occur (Meissele et al. 2005).

12.6.1 Case Study I

Investigations on the predatory carabids in rotational intensive cropping systems of the central non-chernozems of Russia during 1990–1991 revealed the occurrence of 52 species of carabid beetles belonging to 21 genera. The dominant carabid species included *Poecilus cupreus* L., *P. versicolor* (Pay), *Pterostichus melanarius* (Ill.) and *Pseudophonus rufipes* (DeG), which formed 80–85 % of the total catch, among which *P. cupreus* was predominant (60–66 %) and was recorded from all the seven rotational field crops. The diversity and abundance of predatory carabids significantly differed among the treatments; however, the maximum species diversity of carabids was recorded from perennial crops and winter wheat.

The seasonal population dynamics of ground beetles depended upon the few dominant species. In winter wheat, *P. cupreus*, *P. versicolor*, *Amara familiaris* (Duft.) and *P. rufipes* dominated with maximum numbers in the last week of May. In perennial clover as well as the other field crops, *P. cupreus*, *P. melanarius* and *P. rufipes* dominated at different periods of vegetative growth depending upon the availability of suitable prey. The Shannon diversity indices were the highest for the crop of oats followed by that for perennial clover (I year) during 1990 (Table 12.2) and similarly for perennial clover (I year) followed by barley with clover during 1991 (Table 12.3).

The dominant predatory carabids (*P. cupreus*, *P. versicolor*, *A. familiaris* and *P. rufipes*) specialized as zoophagous species that could be observed from their gut contents, which contained chitinous undigested parts of mostly arthropod prey (aphids, elaterids, true bugs and dipteran flies). Impact of commonly used pesticides (herbicides, Dialen and Lontrel; insecticides, Basudin, Fenvalerate, Cypermethrin and Decamethrin) at recommended doses on the carabid population showed both the herbicides to be safe to the carabids, while, among the insecticides, Basudin was the most toxic to all carabids under laboratory investigations as well as the mini-field trials with 80–100 % mortality after 7 days. Among the synthetic pyrethroids, Cypermethrin was relatively more toxic to the carabids, and Fenvalerate was the least toxic (Swaminathan 1992; Isaichev and Swaminathan 1993; Swaminathan and Isaichev 2000).

Table 12.3 Distribution of carabids in rotational intensive cropping systems, 1991

Rotational cropping systems	Population abundance of carabid species (%)						
	Poecilus cupreus	*Poecilus versicolor*	*Pterostichus melanarius*	*Harpalus affinis*	*Pseudophonus rufipes*	Other species	Shannon diversity index
Barley	58.81	2.35	5.85	7.76	3.42	21.81	1.2123
Winter wheat	69.01	3.65	3.17	7.63	1.96	14.58	1.0404
Winter wheat	74.14	1.34	8.52	3.74	2.78	9.48	0.9353
Perennial clover II year	58.58	4.12	6.71	4.47	8.21	17.91	1.2781
Barley + clover	52.03	1.54	17.44	2.92	7.12	18.95	**1.3153**
Perennial clover I year	50.44	1.42	9.17	6.11	7.13	25.73	**1.3331**
Oats + *Vicia faba*	78.55	4.12	2.34	2.28	5.75	6.96	0.8448

12.6.2 Case Study II

In the tropics and subtropical habitats, carabids are in plenty during the monsoon period from June through September and again in March and April. Usually, there is a significant increase in their populations after the monsoon rains. In field experiments on pulses (green gram, black gram) and oilseeds (soybean and groundnut) at Udaipur, Rajasthan, the light trap (at crop height level) collections yielded 14 carabid beetles belonging to 11 genera, which were identified as follows: *Abacetus* sp., *Bembidion* sp., *Brachinus limbicollis* Chaud., *Callistomimus chalcocephalus* Wied., *Casnoidea indica* Thunb., *Casnoidea* sp., *Chlaenius viridis* Chaud., *Chlaenius vulneratus* Dej., *Dioryche* sp., *Clivinia attenvirta* Herbst., *Pheropsophus lineifrons* Chaud., *Platymelopus* sp., *Stenolophus* sp. and *Stenolophus 5-pustulatus* Wied.

Adults of *Casnoidea indica* Thunberg exhibited great preference for *Aphis gossypii* on cotton leaves. The captive adults consumed more than 250 aphids per day. The occurrence of this beetle was more frequent. They are very agile and are good climbers reaching shoot tips in search of prey. The incidence coincides positively with the event of rains, and the species holds great promise for biocontrol of jassids and aphids on account of their preponderance and voracious feeding observed. Adults of this species have been observed feeding in the early hours on jassid nymphs (*Empoasca* sp.) on the underside of green gram leaves and, on the aphid, *Aphis craccivora*, infesting the developing pods during *kharif* 1998. Observations on the feeding potential of adult *Chlaenius viridis* Chaudoir showed that a single adult beetle could consume an average of 5.66 to 9.16 tobacco caterpillar (*Spodoptera litura* (Fab.)) larvae per day (Swaminathan et al. 2001).

12.7 Conclusion

Predatory carabids are considered as important biological control agents distributed in pulses (green gram, black gram) and oilseeds (soybean and groundnut). More than 14 carabid beetles belonging to 11 genera were recorded from India. *Spodoptera littoralis* and *P. cupreus* caterpillars, *Calliphora* sp. pupae and cereal aphids are the common preys for these predators. Synthetic pyrethroids, Cypermethrin, were relatively more toxic than Fenvalerate. Hence, this group of predators can be utilized in pest management.

12.8 Future Focus

Thorough knowledge about the distribution and diversity of predatory carabids, biology and life table studies are imperative and can be undertaken in relation to biotic and abiotic factors in order to utilize them in pest management programme; mass production can be undertaken and laboratory, field cage and filed studies are imperative.

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