Chapter 3

BIOLOGY AND ECOLOGY OF IMPORTANT PREDATORS AND PARASITES ATTACKING ARTHROPOD PESTS

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INTRODUCTION

The important influences of natural enemies on cotton pests have been recognized for a long time (Quaintance and Brues, 1905; Whitcomb, 1971). However, their role in suppression of pest populations was not clearly recognized until, with widespread use of broad-spectrum insecticides, pest resurgence and secondary pest outbreaks were observed (Newsom and Brazzel, 1968).

Considerable research has been conducted to determine what species of natural enemies are important and how these can be used more effectively in cotton insect pest management. Although both vertebrate and invertebrate natural enemies prey on or parasitize the large number of arthropod pests of cotton, the emphasis here will be on predaceous and parasitic arthropods because they probably cause the most pest mortality (Sterling *et al.*, 1989). Some phytophagous (feed on plants) pests also prey on other pests of cotton. These include the cotton fleahopper, *Pseudatomoscelis seriatus*

(Reuter) (McDaniel and Sterling, 1982) (Plate 3-1[1]) and the tarnished plant bug, *Lygus lineolaris* (Palisot de Beauvois) (Cleveland, 1987). The biology and ecology of these are discussed in Chapter 2 (this book) by Leigh *et al.*

An estimated 300 to 600 species of arthropod natural enemies are found in cotton fields (Whitcomb and Bell, 1964; van den Bosch and Hagen, 1966). Of those, 15 or 20 are key species in the suppression of bollworm, *Helicoverpa zea* (Boddie), and tobacco budworm, *Heliothis virescens* (F.), in cotton (Ridgway and Lingren, 1972), and relatively few species would be added to this number if the entire pest complex of cotton were considered. The emphasis in this chapter will be on the biology and ecology of a few selected natural enemies, which are representative of the key species involved in different areas of the Cotton Belt. The species selected are: (a) *Geocoris punctipes* (Say) and the western bigeyed bug, *Geocoris pallens* (Stål); (b) the anthocorids, insidious flower bug, *Orius insidiosus* (Say) and minute pirate bug, *Orius tristicolor* (White); (c) the chrysopids, common green lacewing, *Chrysoperla carnea* Stephens and *Chrysoperla rufilabris* (Burmeister); (d) fire ants; (e) several species of spiders; (f) *Microplitis croceipes* (Cresson); (g) *Cardiochiles nigriceps* (Vierick); (h) *Trichogramma* spp.; and (i) tachinids, *Archytas marmoratus* (Townsend) and *Eucelatoria bryani* Sabrosky. Other species of predaceous and parasitic arthropods of cotton such as various species of coccinellids (lady beetles), other species of beetles, predaceous thrips and mites, various species of assassin bugs (family Reduviidae), damsel bugs (family Nabidae), and predaceous stink bugs (family Pentatomidae), as well as a number of other parasitic wasps in the families Ichneumonidae and Braconidae are also important depending on the geographical location and the specific phytophagous pest. Specific information on many of these species can be obtained from publications such as those by Quaintance and Brues (1905), Whitcomb and Bell (1964), van den Bosch and Hagen (1966), and Bohmfalk et al. (1983). Although it is beyond the scope of this chapter to discuss the biology and ecology of all these other beneficial arthropods, it should suffice to indicate that these too are important and should not be ignored when considering the natural enemy complex associated with cotton.

Three approaches are available for the utilization of natural enemies in pest management: importation of exotic natural enemies and augmentation and conservation of existing natural enemy populations. Our emphasis is on augmentation and conservation and the development of programs to actively manage the natural enemy complex (Price, 1981; Nordlund *et al.*, 1986; Vinson, 1988) similar to those developed for the pests. A primary aspect, discussed in Chapter 7 (this book) by Sterling *et al.*, is an improved understanding of the relationship between the densities of natural enemies and pests for the development of decision criteria. The other aspects emphasized here relate to environmental manipulations which maintain or increase the densities of the natural enemy complex or their suppressive effects on pest populations. This may involve provision of various environmental requisites, use of semiochemicals [chemi-

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[1] All color plates can be found in the Appendix of this chapter.

cals involved in the interaction between organisms (Law and Regnier, 1971)], and modification of production or cropping practices.

Because of changes in approaches to cotton insect management brought about by the boll weevil eradication programs, the development of pyrethroid resistance in the tobacco budworm, increased pest status of the sweetpotato whitefly, *Bemisia tabaci* (Gennadius) and the cotton aphid, *Aphis gossypii* Glover, or changes needed as a result of recent sustainable agriculture initiatives, it is likely that renewed emphasis will be given to maximum utilization of the entire natural enemy complex (both predators and parasites) of all cotton pests. The primary emphasis in this chapter is on the factors that influence the abundance, phenology and efficacy of the selected species of natural enemies of cotton pests.

PREDATORS AND PARASITES AS NATURAL ENEMIES

Arthropod natural enemies in cotton fields are classified either as predators or parasites (van den Bosch and Hagen, 1966). Recognition of the distinction between the two groups is useful in understanding their biology, ecology and efficacy (Doutt, 1964).

A predator characteristically seizes or pierces its prey and either devours it or sucks it dry of its body fluids. An individual predator consumes a number of prey in completing its development. Both the adult and immature stages often feed on the same kind of prey. Generally, predators associated with cotton have a broad prey range. Predators either have chewing or piercing-sucking mouthparts and those with piercing-sucking mouthparts often inject powerful toxins and digestive enzymes that quickly immobilize the prey.

Parasites on the other hand, are insects that develop within or upon a single host and therefore are parasitic only in the immature stages. However, more than one parasite may develop in or on a single host. Adult parasites are generally free-living and feed on nectar, honeydew and sometimes host fluids. There are parasites that develop in all host life stages including the egg, larval or nymphal, pupal and adult. However, each species of parasite attacks only one life stage. Sometimes, parasite development extends over more than one life stage, such as egg-larval, larval-pupal, and nymphal-adult, but here again, one stage is attacked and development extends over two stages. The tendency is for the host range to be more limited than that of predators.

FACTORS INFLUENCING NATURAL ENEMY ABUNDANCE, PHENOLOGY AND EFFICACY

A review of the numerous factors influencing natural enemy abundance, phenology and efficacy is necessary for recognition of the opportunities for their maximum utilization. Some of these considerations relate to the intrinsic characteristics of each species and the interactions with the agroecosystem. These factors include: (a) habitat suitability; (b) availability of suitable prey or hosts; (c) insecticidal applications;

(d) geographical location; and (e) cotton varieties. The effects of some of these factors on entomophagous (feed on insects) arthropods have been discussed by Ables *et al.* (1983) and Goodenough *et al.* (1986). The system has numerous interactions and, because of the complexity, we have not been able to develop production systems that maximize the benefits from natural enemies. It is because of this complexity that recent research related to the development of decision-making technology, which incorporates the effects of natural enemies, has been on modeling (Sterling *et al.*, 1993; Wagner *et al.*, Chapter 6, this book; Sterling *et al.*, Chapter 7, this book). Computer models are needed that integrate the biology, ecology, and behavior of natural enemies with the objective of using this information to analyze and forecast the impact of the key natural enemies on the dynamics and economics of key pests.

HABITAT SUITABILITY

Because cotton is grown as an annual crop, it is available as a habitat for predators and parasites only during the growing season. In a single crop conventional production system, the noncrop period consists essentially of bare fields with minimal resources for supporting insect life. As the cotton plant grows and matures, changes occur that affect the availability of resources which are necessary for arthropod survival and reproduction. Such changes include alterations in the nutritional value of the cotton plant (Yokoyoma, 1978) and shifts in the makeup or abundance of host or prey popultions (Gonzalez and Wilson, 1982). Due to the ephemeral (transient) nature of the cotton ecosystem and the changes it undergoes during the growing season, colonization by arthropod predators and parasites is required. Sources of colonizer insects from the cultivated and uncultivated areas around cotton fields are of critical importance.

Fuchs and Harding (1976) determined that noncultivated habitats supported more predators than did cultivated habitats in the Lower Rio Grande Valley of Texas. They found the greatest numbers of predators in mixed grass habitats. Occurrence of vast cotton monocultures in some areas reduces the availability of colonizers. Intuitively, the number and kind of predators and parasites available to colonize cotton fields are determined by the surrounding area and its suitability for the development of natural enemy populations. The effectiveness of predators and parasites is dependent on their ability to move rapidly from the surrounding habitats into cotton fields. The timing of such movement is critical and thus the phenology (science concerned with the relationship of climate to biological phenomena) of the surroundings is important. Volatile chemicals (synomones) emanating from cotton plants are also important in the response of natural enemies to the cotton habitat (Vinson, 1988; Ridgway *et al.*, Chapter 11, this book).

Recognition of the importance of areas surrounding cotton fields as reservoirs of natural enemies (Fuchs and Harding, 1976; Gaylor and Gilliand, 1976; Pitre *et al.*, 1978; Roach, 1980) has led to studies of the movement of natural enemies into cotton. Lopez and Teetes (1976) documented the movement of predators from sorghum into cotton. In addition, means have been sought to exploit similar situations by strip cropping (Laster and Furr, 1972; Robinson *et al.*, 1972a, b; Schuster, 1980; DeLoach and Peters, 1972; Pair *et al.*, 1982).

Ehler and Miller (1978) concluded that key natural enemy species have adapted to habitats of low durational stability represented by the annual crop cotton habitat. These species then have become a key in the suppression of arthropod pest populations.

A mid-season decline of predators associated with cotton has been reported in different areas of the Cotton Belt (Dinkins *et al.*, 1970a, b; Schuster and Boling, 1974; Smith and Stadelbacher, 1978). Although various reasons have been cited as the cause, it is in part a function of plant maturity (Dean and Sterling, 1992). As the boll load increases, predator numbers decrease. The boll load measure reflects the completion of the period of blooming and a change in the availability of suitable food for both the pests and natural enemies.

AVAILABILITY OF SUITABLE PREY OR HOSTS

Another factor that influences predators and parasites is the availability of suitable prey or hosts, including the species, stage and number available during different periods of the cotton growing season. A key characteristic of predators and parasites relative to this factor is the host range. A natural enemy with a broad host range would have a greater chance of effective colonization. However, from a grower viewpoint, a broad prey or host range may be detrimental because it reduces the regulatory effects on specific pest species. Differences in the host or prey range of predators and parasites would certainly have an influence on the population dynamics of the two types of natural enemies. Thus, preference and specificity of the natural enemies are important considerations. Ables *et al.* (1978) demonstrated this effect for several predator species with different densities of the cotton aphid and tobacco budworm eggs as prey.

Chemicals [kairomones—substance(s) produced or acquired by an organism that, when it contacts an individual of another species in the natural context, evokes in the receiver a behavioral or physiological reaction that is adaptively favorable to the receiver but not to the emitter (Brown *et al.*, 1970)] associated with specific pest species also influence the host or prey finding and selection behavior of natural enemies (Vinson, 1988). See Chapter 11, this book, for a discussion of behavior-mediating chemicals.

A primary concern relative to natural enemy abundance and efficacy are the <u>functional</u> and <u>numerical responses</u> (Solomon, 1949) of the predators or parasites to host or prey density. The <u>functional response</u> refers to changes in the number of prey consumed or hosts parasitized per unit time in relation to the change in prey density. The <u>numerical response</u> refers to the increase in numbers of predators or parasites in response to increases in prey or host density. From the standpoint of the short term effects of natural enemies on pest densities, the functional response is important. However, in relation to colonization of the cotton habitat, the numerical response is important.

The suitability of the host or prey for development of the predator or parasite is also important. A high level of suitability should result in higher rates of development, survival and fecundity which all contribute to an increase in the number of natural enemies in response to an increase in prey or host density.

Some natural enemies feed on plant juices, nectar or pollen. This feeding is important to the survival of the species during periods when prey or host abundance is limited. It may also be important in earlier colonization and persistent occurrence in the cotton habitat.

INSECTICIDAL APPLICATIONS

One of the most important factors influencing natural enemy presence and abundance in cotton is application of insecticides; a major area of the conservation approach to biological control. The adverse effects of insecticides on beneficial arthropods are affected by the rate, time, frequency and method of application (Ables *et al.*, 1983). Other factors are: (a) the acute toxicity and persistence of the insecticides used (Plapp and Vinson, 1977; Plapp and Bull, 1980; Chang and Plapp, 1983; Bull *et al.*, 1989; Pree *et al.*, 1989); (b) size of the area treated; and (c) the diversity of the agroecosystem (Bradley *et al.*, 1987). These adverse effects on natural enemies in cotton and subsequent effects on pest populations by the direct application of insecticides to the field have been amply reviewed especially in relation to the bollworm/tobacco budworm (Bradley *et al.*, 1987). Insecticide use in surrounding areas also influences populations in cotton fields because of drift and the effects on potential colonizers. Repetitive use of insecticides both in cotton and the surrounding areas may be an important factor in determining natural abundance of predators and parasites. Shifts in the pattern of use of insecticides also may have an impact on the species composition of the natural enemy complex.

A major concern, as we attempt to manage resistance of the tobacco budworm to the pyrethroids, is the effect of resistance management strategies on natural enemies. Use of different classes of insecticides or mixtures during different periods in the growing season would likely have a major impact on the composition and abundance of the natural enemy complex. In addition, the need to treat eggs and very small larvae to obtain satisfactory control of resistant insects (because of the greater susceptibility of the early instar larvae) limits the potential for maximum utilization of predators and parasites.

GEOGRAPHICAL LOCATION

Considerable variability has been identified in the natural enemy complexes of different areas of the Cotton Belt (Ables *et al.*, 1983). These differences reflect variability in climate and local cultural practices which include tillage systems, chemical weed control, irrigation, planting dates and densities, cultivars (varieties) used, row spacing, crop rotation, fertilization, planting design and management of non-crop plants. The interaction of these factors provide a characteristic natural enemy complex at each location. Our understanding of the reasons for the differences will improve our ability to utilize predators and parasites in pest management programs.

Mode of overwintering and the suitability of habitats available for overwintering are related to geographical location and cultural practices but have not received sufficient attention by researchers. In most areas of the Cotton Belt, harsh winter conditions and scarcity of suitable prey or hosts are major factors in reducing the numbers of natural enemies available for colonization in the spring. It is especially important to understand the overwintering dynamics of pest and natural enemy populations to be able to produce multi-year models as an extension to current seasonal models such as TEXCIM for Windows (Sterling *et al.*, 1993). Although forecasting models are currently available for some key pests of cotton, they are in a more elementary state for natural enemies. Until these models become available, counts of natural enemies in cotton fields can be entered into models to forecast their short-term impact using the TEXCIM approach.

COTTON VARIETIES

Populations of natural enemies also are affected by cotton varieties (Ables *et al.*, 1983; Treacy *et al.*, 1985), especially varieties with host plant resistance characters. These varieties may limit the number of prey or hosts available as well as the habitat quality afforded by the plant. Shepard *et al.* (1972) reported that hirsute (hairy) genotypes generally supported fewer natural enemies than did early maturing glabrous (smooth) genotypes. Mussett *et al.* (1979) reported that, when compared to a standard commercial variety, predator populations were reduced by up to 68 percent in cotton lines bred for bollworm/tobacco budworm resistance. Numerous studies comparing the effect of the nectariless and the nectaried characters on the natural enemy complex have generally concluded that the nectariless character is detrimental to the abundance or effectiveness of the natural enemy complex (Schuster *et al.*, 1976; Calderon, 1977; Henneberry *et al.*, 1977; Lingren and Lukefahr, 1977; Mussett *et al.*, 1979; Agnew *et al.*, 1982; DeLima and Leigh, 1984; Thead *et al.*, 1985; Treacy *et al.*, 1987a).

One important component of future pest management programs may lie in habitat manipulation both inside and outside the cultivated field (Whitcomb, 1974). Whitcomb stated that population manipulation systems should be based on a thorough understanding of the agroecosystem. The predators and parasites that play a role in checking the abundance of pests, their life histories, and factors affecting their populations must be known. He further stated that the source of beneficial insects and the cause of population fluctuations is almost a separate discipline of science in itself.

PREDATORS

The most immediate opportunities for substantial use of entomophages are related to increased use of predators for management of bollworm/tobacco budworm (Ables *et al.*, 1983). More recent research has identified other predators that are important in the suppression of boll weevil and cotton fleahopper populations that should be considered. Several important species of insect and spider predators have been selected for discussion here. These include two species each of bigeyed bugs, chrysopids and anthocorid bugs. Fire ants are discussed as a group with primary emphasis on the red imported fire ant, *Solenopsis invicta* Buren. The other predators discussed are spiders; these are also discussed as a group.

INSECTS

Bigeyed Bugs—The subfamily Geocorinae of the family Lygaeidae, is of interest because unlike most members of this family which are seed feeders, all known species are predaceous (Readio and Sweet, 1982). The species are not obligatory predators in that they feed on seeds (Sweet, 1960), plant juices (Ridgway and Jones, 1968; Stoner, 1970) and cotton extrafloral nectar (Yokoyama, 1978).

These predators are commonly called bigeyed bugs because of the large conspicuous eyes on their distinctively broad heads (Plate 3-2). The compound eyes protrude laterally beyond the pronotum (the shield-like structure on top of the first thoracic segment just behind the insect's head). Although several *Geocoris* species are associated with cotton, *Geocoris punctipes* and the western bigeyed bug, *Geocoris pallens*, apparently are the most important species.

Geocoris punctipes is widely distributed throughout much of the southern two-thirds of the United States and its range extends southward into Colombia, South America (Readio and Sweet, 1982). The western bigeyed bug has been collected from most of the western states and its range extends eastward to Indiana, Illinois, Missouri and Arkansas (Readio and Sweet, 1982). Numerous studies on the occurrence of the two species in the Cotton Belt indicate that *Geocoris punctipes* is less abundant than the western bigeyed bug in California (van den Bosch and Hagen, 1966), but it becomes predominant in eastern areas of the Cotton Belt (Butler 1966a; Roach, 1980; Parencia *et al.*, 1980; Schuster and Boling, 1974; Pitre *et al.*, 1978; Dinkins *et al.*, 1970a, b; Roach, 1980; Crocker and Whitcomb, 1980).

Development in both species is hemimetabolous (incomplete metamorphosis) in that they go through the egg, nymphal, and adult stages (Champlain and Sholdt 1966; Tamaki and Weeks, 1972). There are five nymphal instars. Davis (1981) described the eggs as ovoid with one end tapering more than the other. Chorionic processes located at the blunt end of the egg form a ring of five to seven hooked, peg-like structures below which conspicuous red eye spots appear about five days before eclosion. The length and width of eggs average 0.038 inch (0.97 millimeter) by 0.015 inch (0.37 millimeter) and 0.035 inch (0.88 millimeter) by 0.015 inch (0.37 millimeter) for *Geocoris punctipes* and western bigeyed bug, respectively. The nymphs are pale gray to greenish gray in color with the abdomen either mottled or streaked with red (Plate 3-3). Second through fifth instars of *Geocoris punctipes* have the head with a dark sulcus (groove) extending from the tylus (a central prominence on the upper side of the head) onto the vertex of the head and the abdomen with broken red streaks running laterally across segments while western bigeyed bugs have the head with a faint sulcus extending from the tylus onto the vertex and the abdomen with red mottling interspersed over the entire surface. The females of western bigeyed bugs and *Geocoris punctipes* average about 1/6th inch (4.07 millimeters) and 3/16ths inch (4.45 millimeters) in length, respectively, while the males average about 5/32nds inch (3.64 millimeters) and about 1/6th inch (4.07 millimeters), respectively. In *Geocoris punctipes* adults, the head is smooth, shiny; the sulcus extends from tylus onto the vertex; the bucculae (ridge beneath the head on either side of the proboscis or mouth of some insects) does not meet directly behind the labium (lower lip) but forms a narrow v-ridge which runs to the posterior margin of the head. Western bigeyed bug adults have a granulose head; sulcus not extending beyond the tylus; the bucculae meeting directly behind the labium; scutellum (the area of the wing-bearing plate of the top of the second or third thoracic segments that is posterior to the V-shaped notal ridge) distinctly longer than wide; head with various light markings, particularly a yellow comma-shaped area on the outer lateral edge of each ocellus (single simple eye), black pronotal calluses (thickened or cuticular swellings on the body of an insect) generally have a light oval spot in the center of each callus; posterior half of pronotum is generally white; scutellum evenly convex with a smooth ridge down entire midline of scutellum; corium (the middle part of the basally thickened front wings of insects) of wing yellowish-white and punctuation on wing distinct.

There have been numerous studies on the effect of temperature and diet on the development of *Geocoris punctipes* and western bigeyed bug (Champlain and Sholdt, 1966, 1967a, b; Butler, 1966b; Dunbar and Bacon, 1972a, b; Tamaki and Weeks, 1972; Crocker *et al.*, 1975; Davis, 1981; Cohen and Debolt, 1983). Rate of development is influenced primarily by temperature and food quality. Although feeding on seeds, plant juices and nectar does occur, prey are necessary for both species to complete their life cycles and to reproduce. Green beans have been used as a source of moisture in most studies, but Cohen and Debolt (1983) showed that water was just as good for rearing. Considerable variation in the rate of development has been observed, probably due to differences in the food and rearing conditions. Dunbar and Bacon (1972a) and Davis (1981) evaluated rates of development of eggs and nymphs for both *Geocoris punctipes* and western bigeyed bug using similar temperature regimes and the same kind of food (Table 1). The data for selected temperatures demonstrate the number of days required and the better adaptation of the western bigeyed bug to higher temperatures. This may contribute to its predominance in the hotter southwestern areas of the Cotton Belt.

Mating may occur on the day of adult emergence and the preoviposition (pre-egglaying) period at 79F (26.1C) for both species is about five days. The adults are relatively long-lived (two or three months), at least in the laboratory. Total fecundity per female at the optimum temperature was a mean of 301 eggs at 90F (32.2C) and 416 at 84.9F (29.4C) for the western bigeyed bug and *Geocoris punctipes*, respectively (Davis, 1981). During periods of peak oviposition, females oviposited between five and ten eggs per day.

Both *Geocoris punctipes* and western bigeyed bug overwinter as adults on winter crops (Whitcomb and Bell, 1964); they may take cover in ground trash during cooler periods (Tamaki and Weeks, 1972). Adult movement into cotton appears to be related to the fruiting cycle (Dean and Sterling, 1992). Studies indicate that the seasonal occurrence of *Geocoris punctipes* and western bigeyed bug is related to blooming of cotton. A late season decline in the numbers of *Geocoris* spp. has been observed in most areas of the Cotton Belt (Fuchs and Harding, 1976; Pitre *et al.*, 1978; Roach, 1980; Smith and Stadelbacher, 1978; Dinkins *et al.*, 1970a, b), which has been attrib-

Table 1. Effects of selected temperatures on development of *Geocoris punctipes* and western bigeyed bugs, *Geocoris pallens* as reported from two separate studies.

Average number of days (percent survival) to complete stage					
		Study no. one[1]		Study no. two[2]	
Life Stage	Temperature F (C)	*Geocoris punctipes*	*Geocoris pallens*	*Geocoris punctipes*	*Geocoris pallens*
Egg	75 (23.9)	18.7 (85.7)	16.3 (81.3)	14.4 (82.2)	12.3 (80.3)
	80 (26.7)	10.5 (83.2)	8.9 (95.9)	8.7 (76.7)	7.1 (86.6)
	95 (35.0)	6.4 (74.7)	4.9 (93.9)	5.7 (65.7)	4.1 (83.0)
	99 (37.8)	6.5 (11.0)	4.2 (85.7)	0.0	0.0
Nymph	75 (23.9)	41.4 (71.4)	49.0 (1.0)	37.3 (71.2)	42.2 (35.3)
	80 (26.7)	27.6 (56.8)	27.3 (28.6)	25.3 (63.6)	24.1 (50.4)
	95 (35.0)	16.6 (48.5)	13.6 (50.5)	17.0 (8.9)	12.1 (60.0)
	99 (37.8)	0.0 (0.0)	12.3 (24.5)	0.0	0.0

[1] Data from Davis, L. D., Jr. 1981.
[2] Data from Dunbar, D. M. and O. G. Bacon. 1972a.

uted to late season insecticide applications (Dinkins *et al.*, 1970b) and a natural decline in numbers late in the season (Smith and Stadelbacher, 1978). Yokoyama (1978) suggested that the decreasing availability of extrafloral nectar is an important factor in this decline. The distribution of the different stages of *Geocoris* on the cotton plant during the season has also been attributed to the effect of extrafloral nectaries. Eggs have been found on the underside of cotton leaves close to extrafloral nectaries. The nymphs and adults have also been observed to be more common on the lower parts of plants where they are apparently associated with the extrafloral nectaries (Cosper *et al.*, 1983). The higher numbers of *Geocoris* spp. observed on nectaried as compared to nectariless cotton genotypes (Schuster *et al.*, 1976; Henneberry *et al.*, 1977) supports the conclusion that extrafloral nectar is important in the development of *Geocoris* spp. populations in cotton. Gonzalez *et al.* (1977) also suggested that the build-up of prey, especially minor pests of cotton, which is influenced by the fruiting cycle, may also contribute to the seasonal pattern of *Geocoris* abundance.

Geocoris punctipes and western bigeyed bug have piercing-sucking mouthparts; they attack by waiting or running up to the prey, extending the beak and quickly inserting the stylets (Crocker and Whitcomb, 1980). Both species have a relatively broad prey range (Stoner, 1970; Tamaki and Weeks, 1972; Crocker and Whitcomb, 1980). Important prey relative to cotton are spider mites, cotton fleahoppers, whiteflies, aphids, plant bugs, thrips and lepidopterous eggs and larvae. Among the lepidopterous eggs and larvae are the bollworm and tobacco budworm (Lingren *et al.*, 1968; Lopez *et al.*, 1976; McDaniel and Sterling, 1982; Bell and Whitcomb, 1964; van den Bosch *et al.*, 1969), pink bollworm, *Pectinophora gossypiella* (Saunders), (Orphanides *et al.*, 1971; Henneberry and Clayton, 1985), cabbage looper, *Trichoplusia ni* (Hübner), (Ehler *et al.*, 1973), and cotton leafworm, *Alabama argillacea* (Hübner), (Gravena and Sterling, 1983). Field and laboratory studies have shown *Geocoris* spp. to be particularly effective predators of lepidopterous eggs and early instar larvae (Eveleens *et al.*, 1973; Bell and Whitcomb, 1964; Ehler *et al.*, 1973; Lopez *et al.*, 1976; Lawrence and Watson, 1979; Chiravathanapong and Pitre, 1980). *Geocoris punctipes* also is a key predator of the cotton fleahopper (Breene *et al.*, 1989b).

An aggregation response by *Geocoris punctipes* adults to selected dosages of aqueous homogenates of terminal instar bollworm and fall armyworm, *Spodoptera frugiperda* (J. E. Smith), larvae applied to whorl stage corn has been observed apparently in response to chemical stimuli (kairomones) (Gross *et al.*, 1985).

Chrysopids—Chrysopids are important predators and two species, *Chrysoperla carnea* (common green lacewing) and *Chrysoperla rufilabris*, are frequently associated with cotton. Green lacewing larvae are commonly called aphidlions. They prey on a wide variety of small soft-bodied insects and mites (Ridgway and Kinzer, 1974). Of particular importance relative to cotton, is their ability to prey on aphids, thrips, whiteflies, mites and eggs and small larvae of several species of lepidopterous pests.

The two species differ significantly in their geographical distribution. Where they occur together, their relative and seasonal abundance often differ (Tauber and Tauber, 1983). The common green lacewing is widely distributed within North America and has been collected in Alaska, every Canadian province, every state in the contiguous United States and as far south as the Federal District in Mexico. The distribution of *Chrysoperla rufilabris* is more restricted and is limited to eastern and midwestern parts of North America, extending from eastern Canada through Florida and northeastern Mexico (Tauber and Tauber, 1983). Its range overlaps with that of common green lacewing from eastern Canada to northeastern Mexico, but in the southeastern United States and Mexico, *Chrysoperla rufilabris* is generally more common. This difference in distribution is attributed to the differential response of the two species to humidity (Tauber and Tauber, 1983). Under high humidity conditions common in the southeastern United States, the developmental potential of *Chrysoperla rufilabris* is slightly higher than the common green lacewing. Low humidity substantially reduces the developmental and reproductive potentials of *Chrysoperla rufilabris*, but has no negative effects on common green lacewing. Thus, the common lacewing is favored in the less humid southwestern parts of the United States.

These generalizations on the distribution of the two species are borne out by research conducted in different parts of the Cotton Belt. In California, the common green lacewing is mentioned as the primary species occurring on cotton (van den Bosch and Hagen, 1966; Ehler *et al.*, 1973; Gonzalez *et al.*, 1977; Wilson and Gutierrez, 1980). In the central and southeastern parts of the Cotton Belt, both species occur together, but there are seasonal differences. During the early season, common green lacewing has been found to predominate, but during mid- to late-season, *Chrysoperla rufilabris* was the most abundant (Burke and Martin, 1956; Bell and Whitcomb, 1964; Dinkins, 1970a, b; Agnew et al., 1981). In these areas, it appears that

Chrysoperla rufilabris is more important relative to the impact on bollworm/tobacco budworm and other pests in cotton.

The adults are about 1/2 to 3/4ths inch (12.5 to 19.1 millimeters) long and are yellowish-green with golden eyes and large, delicate, netted wings (Plate 3-4). *Chrysoperla* adults are identified by criteria provided by Bickley and MacLeod (1956) and photos and keys of Agnew *et al.* (1981). According to Bram and Bickley (1963), both species have the antennae, except for the second segment, entirely pale or with the basal fourth pale, apical third may be brownish, but not dark brown and the antennae are unmarked (no black or brown ring on the second segment). Adults with the above characteristics and with all veins entirely pale, or at most with only an occasional dark crossvein, and with a definite narrow black or dark-red band from eye to mouth over the genae; varying amounts of red suffusion adjacent to the black band; and hind wing bluntly rounded at apex are common green lacewings (Plate 3-5). Adults of *Chrysoperla rufilabris* have the gradates and some other veins marked with black or brown; pronotum, thorax and abdomen without orange spots; and a red stripe on genae from eye to mouth. According to Agnew *et al.* (1981), separation of *Chrysoperla rufilabris* is by: (a) gradate veins dark colored, (b) pronotum and abdomen without dark orange markings, and (c) genae with red markings running from eye to mouth. The common green lacewing has all veins pale with only an occasional dark crossvein and the genae with a straight dark line, often suffused with red, running from eye to mouth.

The stage most likely to be found in cotton fields is the larval stage. In both species, there are three larval instars. The larvae are naked (not trash carriers), campodeiform (body elongate and somewhat flattened, thoracic legs well developed, and the larvae are usually active), the abdomen is not humped and with long and slender jaws (Tauber, 1974). The most striking specialization of the larvae is the prolongation of the maxillae and the mandibles to form sickle shaped sucking tubes that are efficiently used in catching and feeding on prey (Smith, 1922). Tauber (1974) provided characteristics by which different instars of the two species can be separated. Relatively distinct differences are evident between the larvae of the two species especially in the later instars (Plates 3-6 and 3-7).

Development in the common green lacewing and *Chrysoperla rufilabris* is holometabolous (complete metamorphosis) involving four distinct developmental stages: egg, larva, pupa and adult. Both species lay eggs singly. The eggs are attached at the extreme posterior end to a hyaline, hardened gelatinous stalk that is from about 1/6th to 1/3rd inch (4 to 8 mm) long (Smith, 1922) (Plate 3-8). The egg is elongate-elliptical in shape and green to yellowish in color. As the embryo develops, the egg becomes gray with darker areas. The larvae, which are extremely cannibalistic, undergo three molts, the last molt taking place inside the cocoon constructed by the third-instar larva. The cocoon is pure white in color and is spherical or slightly elongated in shape (Plate 3-9). The cocoons are found in areas of the plant where plant parts form an irregular cavity and inside the bracts (between the bracts of squares or bolls) of cotton fruit. The pupae are exarate with freely movable legs and emerge from the cocoon by biting a round lid in the cocoon. The molt to the adult occurs after emergence.

Development of common green lacewing and *Chrysoperla rufilabris* under different rearing conditions and different larval food are summarized in Table 2. Of major concern relative to the direct effects of common green lacewing and *Chrysoperla rufilabris* on cotton pests is the length of the larval stage which is predatory and the ability to develop on a wide range of prey.

Table 2. Developmental time of the stages of common green lacewing, *Chrysoperla carnea*, and *Chrysoperla rufilabris* affected by temperature and food source.

		Average developmental time (Days)				
Temperature F (C)	Food source	Egg	Larva	Pupa		Source/ reference
		Chrysoperla carnea				
75 ± 7.2 (24 ± 4)		5.3	18.3	9.6		Toschi (1965)
Avg. min. of 75F to Avg. max. of 88F	aphids	4.9	13.7	8.1		Burke & Martin (1956)
				male	female	
59 (15)	Angoumois grain moth eggs	13.1	28.8			Butler & Ritchie (1970)
68 (20)		6.3	13.9	13.3	13.8	
77 (25)		4.2	10.6	8.8	8.8	
86 (30)		3.1	7.1	6.6	6.9	
90 (32.2)			6.5	6.1	6.2	
90 (35)			6.6	5.9	6.2	
77 ± 2.7 (25 ± 1.5)	bollworm/tobacco budworm eggs		8.6			Boyd (1970)
	bollworm/tobacco budworm larvae		11.4			
	cotton aphids		8.8			
	carmine spider mites		16.0			
	Angoumois grain moth eggs		8.2			Tauber & Tauber (1983)
72 (22.2) (35%RH[1])	Angoumois grain moth eggs		25.5			
72 (22.2) (55%RH)			25.9			
72 (22.2) (75%RH)			25.2			
		Chrysoperla rufilabris				
Avg. min. of 75F to avg. max. of 88F	aphids	3.7	10.4	6.5		Burke & Martin (1956)
72 (22.2) (35%RH)	Angoumois grain moth eggs		28.4			Tauber & Tauber (1983)
72 (22.2) (55%RH)			26.4			
72 (22.2) (75%RH)			24.2			
81 ± 3.6 (27 ± 2) (70%RH)	Angoumois grain moth eggs		21.6			Elkarmi *et al.* (1987)
80 (26.5) (80%RH)	cabbage looper eggs	5.7	15-17.75			Ru *et al.* (1976)
72.5 (22.5)	cowpea aphid		23.3			Hydorn (1971)

Table 2. Continued

Temperature F (C)	Food Source	Average developmental time (Days) Egg	Larva	Pupa	Source/ reference
	green peach aphid		22.0		
	citrus white fly		26.8		
	green lynx spider		28.5		
	greater wax moth		24.2		
	red flour beetle		27.3		
	vinegar fly		26.8		
79 (26)	bollworm		21.7		Hydorn (1971)
	potato tuberworm		19.4		

[1]RH refers to relative humidity.

For the common green lacewing, Burke and Martin (1956) reported a preovipostion period of 13 days with an oviposition period of 20.6 days and a fecundity of 32 eggs per female. According to Hydorn (1971), this was the first record of moderately high fecundity and long longevity of captive adults. The adults were fed a mixture of honey, water and an artificial nutrient powder. Other research (Tauber and Tauber, 1983) conducted at 71.8F (22.1C) and relative humidities of 35, 55 and 75 percent showed a preoviposition period ranging from 5.3 to 7.4 days, a total fecundity, over a 30-day period, of 273 to 328 eggs per female, and a mean number of eggs per female over a 3-day period of 27 to 33 eggs. The adult food was a 1:1:1:1 mixture of Wheast®, protein hydrolysate of yeast, sugar and water. Elkarmi *et al.* (1987) reported a fecundity of 13.3 eggs per female per day over a 30-day period for the common green lacewing at 80.6F (27C) and 75 percent relative humidity. For *Chrysoperla rufilabris*, Burke and Martin (1956) reported that mating occurred within the first two days of adult activity, a preoviposition period of 8.2 days, an oviposition period of 11.3 days and a total fecundity of 31.2 eggs per female. At 72F (22.2C) and at 35, 55, and 75 percent relative humidity, Tauber and Tauber (1983) reported that the preoviposition period for *Chrysoperla rufilabris* ranged from 5.8 to 12.4 days, total fecundity over a 30-day period ranged from 87 to 280 eggs per female and a mean oviposition rate per female over a 3-day period ranging from 8.8 to 28.3 eggs. Elkarmi *et al.* (1987) reported an optimum fecundity at 80.6F (27C) and 70 percent relative humidity of 25.2 eggs per female per day over a 30-day period and a three-day preoviposition period for *Chrysoperla rufilabris*. Hydorn (1971) found that average longevity for *Chrysoperla rufilabris* was over 30 days on a number of larval diets, but longevity was reduced when larvae were reared on vinegar flies, *Drosophila melanogaster* Meigen, and red flower beetles, *Tribolium castaneum* (Herbst), and the average number of eggs per female ranged from 29 to 208 with an average number of eggs per female per day of 1.6 to 9.

Overwintering is another important aspect of the development of the common green lacewing and *Chrysoperla rufilabris* relative to biology and ecology. Both species overwinter in diapause (New, 1975) which is induced by the short photoperiods occurring at the end of summer. Both sexes of common green lacewing undergo a change in color when in adult diapause and become brownish-yellow with rusty red spots on the dorsum (upper side). Although the mode of overwintering of *Chrysoperla rufilabris* has not been studied as extensively as that of the common green lacewing, Putman (1937) reported that *Chrysoperla rufilabris* overwinters in diapause in the prepupal stage in the cocoon; however, Burke and Martin (1956) reported that this species overwinters as an adult in Central Texas.

The adults of the common green lacewing and *Chrysoperla rufilabris* are not predatory and they primarily feed on honeydew, pollen and sweet plant exudates. The common green lacewing has been studied more extensively. The adult response of the common green lacewing toward honeydew has led to research on the use of artificial honeydew to attract adults to field crops and to increase oviposition (Hagen *et al.*, 1971; Hagen and Hale, 1974). Artificial honeydew, containing enzymatic protein hydrolysates of Brewer's yeast or Wheast®, (Hagen and Tassan, 1970), has an attractive ingredient, which is a breakdown product of the amino acid tryptophan (Hagen *et al.*, 1976; van Emden and Hagen, 1976). The affinity of the common green lacewing for cotton was demonstrated in the response during early season of adults to traps baited with caryophyllene, a sesquiterpene hydrocarbon that is a major component of the aroma of a cotton field (Flint *et al.*, 1979).

Jones *et al.* (1977) reported that from 9 a.m. to 6 p.m., the adult common green lacewings are inactive and found primarily in shady areas on the undersides of leaves. This makes them difficult to see during the day. Feeding occurs mostly between 6 to 10 p.m. and between 2 to 9 a.m., peaking between 7 and 8 a.m. Mating occurs primarily between 7 p.m. to 2 a.m. with a peak between 8 to 10 p.m. Males mate when three to four days old and remate readily after a two- to four-day resting period. Most females mate at four days of age and few remate during a 30-day period. Oviposition usually occurs between 8 p.m. to 1 a.m. with a major peak between 9 to 10 p.m.

Adult dispersal behavior is important relative to the colonization of cotton by the common green lacewing. Duelli (1980a, b) reported that adult emergence occurs at night with a prominent peak during the first hour of the scotophase (dark phase). Take-off is elicited by a decrease in light intensity and occurs shortly after sunset. These adaptive dispersal flights during the first two to three nights of adult life are straight downwind for an average distance of 26 miles (40 kilometers) per night and at an average height of 19.7 to 39.4 feet (6 to 12 meters). During these flights, there is no response to honeydew, thus the flights are referred to as obligatory migration flights. After two to three days, honeydew provides a strong landing stimulus and the flights which are now at a height lower than 9.8 feet (3 meters), are appetitive. Honeydew is located by upwind flight that rarely exceeds 3.3 feet (1 meter) above crop level.

Understanding the predatory capabilities of the larval stage is important in assessing the impact of common green lacewing and *Chrysoperla rufilabris* as predators in cotton. The primary research emphasis has been on the common green lacewing and the interaction with lepidopterous cotton pests. The larvae are efficient predators of eggs and early instars of the bollworm and tobacco budworm (Fletcher and Thomas, 1943; Lingren *et al.*, 1968; van den Bosch *et al.*, 1969; Lopez *et al.*, 1976). McDaniel and Sterling (1982) and McDaniel *et al.*, (1981) verified predation of radioactive tobacco budworm eggs and larvae by *Chrysoperla* spp. larvae in cotton fields. Larvae of the common green lacewing are also important predators of eggs and young larvae of pink bollworm (Orphanides *et al.*, 1971; Henneberry and Clayton, 1985), cabbage looper (Ehler *et al.*, 1973), and beet armyworm, *Spodoptera exigua* (Hübner), (Eveleens *et al.*, 1973). Butler and Henneberry (1988) determined that larvae consumed all stages of the sweetpotato whitefly in the laboratory.

Boyd (1970) reported the following predatory capabilities of common green lacewing on cotton: (a) prey preference in descending order was 1st instar bollworm/tobacco budworm larvae > cotton aphids > bollworm/tobacco budworm eggs > carmine spider mites, *Tetranychus cinnabarinus* (Boisduval); (b) all larval instars preyed on bollworm/tobacco budworm eggs, but were able to capture or kill only small to medium sized bollworm/tobacco budworm larvae; (c) larvae spent about 50 percent of their time in search of prey; and (d) larvae were found primarily on the top half of cotton plants (77 percent) and inside the bracts of squares (41 percent). Stark and Whitford (1987) reported a mean search rate of 2.69 x 10^{-5} acres (1.08 x 10^{-5} hectare) per predator per day or 0.36 row-feet (0.11 row-meter) per predator per day for third instar common green lacewing larvae feeding on different densities of tobacco budworm eggs on caged cotton. The importance of prey preference of the larvae was established by Ables *et al.* (1978) who reported that larvae preyed on significantly fewer bollworm/tobacco budworm eggs when cotton aphids were present as alternate prey.

There is evidence that a kairomone(s) associated with bollworm oviposition affects the prey-finding behavior or acceptance of eggs by common green lacewing larvae and moth scales also have kairomonal properties (Lewis *et al.*, 1977; Nordlund *et al.*, 1977).

Effects of insecticides and host plant resistance characters on common green lacewing and *Chrysoperla rufilabris* are important. Populations of common green lacewing showing tolerance to pyrethroids appear to be fairly common (Plapp and Bull, 1978; Shour and Crowder, 1980; Ishaaya and Casida, 1981; Grafton-Cardwell and Hoy, 1985; Pree *et al.*, 1989) and resistance to some types of organophosphorus and carbamate insecticides has been reported (Lingren and Ridgway, 1967; Plapp and Bull, 1978; Grafton-Cardwell and Hoy, 1985, 1986; Pree *et al.*, 1989). Two host plant resistance characters in cotton affect *Chrysoperla* spp. Treacy *et al.* (1987a) showed that fewer bollworm eggs were destroyed by *Chrysoperla rufilabris* larvae on a pilose (soft hairy) cotton than on a hirsute (coarse hairy) cotton and egg predation was greater on smoothleaf cotton than on hirsute cotton. Cotton leaf trichomes (epidermal hairy structures) inhibited movement of the *Chrysoperla rufilabris* larvae on the leaf surfaces, and reduced predation by *Chrysoperla rufilabris*. The effect of the trichomes was reduced for third instar larvae. Elsey (1974) showed that the first and second instars of common green lacewing are able to search much faster on cotton than on tobacco because of the decreased density of glandular trichomes in cotton. The nectariless character significantly reduced densities of common green lacewing more so than *Chrysoperla rufilabris* (Schuster *et al.*, 1976). Boyd (1970) suggested that during periods of low prey availability on cotton, larvae of common green lacewing could supplement their diet with cotton plant nectar. Calderon (1977) found that common green lacewing larvae and adults preferred to feed on aphids and aphid honeydew, rather than on cotton nectar; however, female longevity and fecundity (egg-laying or reproductive ability) were both reduced on nectariless cotton.

Anthocorid Bugs—Two anthocorids are important predators of cotton pests: the insidious flower bug, *Orius insidiosus* and the minute pirate bug, *Orius tristicolor*. The insidious flower bug is more common in the eastern United States while minute pirate bug is primarily a western species; however, their distributions do overlap (Herring, 1966). Studies conducted in cotton throughout the Cotton Belt indicate the predominance of minute pirate bug in the southwest and of insidious flower bug in the South and Southeast. The insidious flower bug has been reported to be a common predator in cotton fields in: South Carolina (Roach, 1980; Roach and Hopkins, 1981); Mississippi (Smith *et al.*, 1976a,b; Smith and Stadebacher, 1978; Pitre *et al.*, 1978; Schuster *et al.*, 1976; Dinkins *et al.*, 1970a, b; Parencia *et al.*, 1980; Schuster, 1980); Louisiana (Watve and Clower, 1976); southeastern Missouri (DeLoach and Peters, 1972); Arkansas (Whitcomb and Bell, 1964; Bell and Whitcomb, 1964); and Texas (Quaintance and Brues, 1905; Ewing and Ivy, 1943; Fletcher and Thomas, 1943; Ridgway and Lingren, 1972; Shepard and Sterling, 1972b; Schuster and Boling, 1974; Lingren and Ridgway, 1967; McDaniel *et al.*, 1981; McDaniel and Sterling, 1982). In contrast, minute pirate bug has been reported to be the most common *Orius* species in: California (van den Bosch and Hagen, 1966; Ehler *et al.*, 1973; Eveleens *et al.*, 1973; Gonzalez *et al.*, 1977; Stoltz and Stern, 1978; Yokoyama, 1978; Byerly *et al.*, 1978; Wilson and Gutierrez, 1980); Arizona (Wene and Sheets, 1962; Butler, 1966a); western counties of Arkansas (Whitcomb and Bell, 1964); the western part of the Lower Rio Grande Valley (Schuster and Boling, 1974); and West Texas (Bohmfalk *et al.*, 1983).

The anthocorids differ from the other members of the Order Heteroptera (true bugs) in that they have a definite embolium (a narrow strip of the corium) of the forewing (Deitz *et al.*, 1976). Both the insidious flower bug and minute pirate bug are black and white and measure less than 1/8th inch in length (1.6 to 2.2 millimeters) (van den Bosch and Hagen, 1966; Isenhour and Yeargan, 1981) (Plate 3-10). Both sexes are similar in appearance, but the males are slightly smaller. Both species are somewhat flattened, and ovoid (egg-shaped) and they have a prominent beak for piercing soft bodied prey and sucking body fluids. The clavus and corium are morphological structures important in separating the two species. According to Kelton (1963), the antennae, legs and the hemelytra of both species are partly black. The clavus is the oblong or triangular anal portion of the front wing and the corium is the elongate, usually thickened, basal portion of the front wing. The clavus is mostly pale as is the corium in insidious flower bugs while in minute pirate bugs, the clavus is mostly black. When the clavi (plural for clavus) of insidious flower bug are dark, males can be separated from minute pirate bugs by the structure of the left claspers (modified structures that assist the males in mating). The females have the lateral margins of the pronotum much more rounded with the calluses flat and poorly delimited (Herring, 1966). The conspicuously bicolored hemelytra with dark clavi will usually separate the minute pirate bug from the insidious flower bug. In the minute pirate bug females, the lateral margins of the pronotum are much straighter and the calluses are much more clearly delimited and elevated than in the insidious flower bug (Herring, 1966).

Development in both species is hemimetabolous involving three stages: egg, five nymphal instars and adult. The inconspicuous eggs are oviposited in soft plant tissue at an angle almost perpendicular to the surface, leaving the concave egg caps showing above the surface (van den Bosch and Hagen, 1966; Isenhour and Yeargan, 1981). Nymphs are similar in body shape to the adults (Plate 3-11). Nymphs of insidious flower bugs are yellowish in the first, second, and third stage and have a distinct orange dorsal scent gland on the third, fourth, and fifth abdominal segments; the fourth and fifth stage nymphs are tan to dark brown (Isenhour and Yeargan, 1981). Newly emerged nymphs of the minute pirate bug are shiny and almost colorless, but become greenish yellow after a few hours; sometimes in the fourth and mainly the fifth nymphal stage, the dorsal abdominal segments become dark brown (Askari and Stern, 1972).

Developmental time of the insidious flower bug and the minute pirate bug is influenced by type of food and rearing conditions (Isenhour and Yeargan, 1981; Kiman and Yeargan, 1985; Askari and Stern, 1972; Salas-Aguilar and Ehler, 1977) (Table 3). The

Table 3. Time of development for the insidious flower bug and minute pirate bug as affected by temperature.

		Average number of days required for completion of the indicated stage	
Species	Temperature F (C)	Egg	Nymph
Insidious flower bug[1]	68.0 (20)	8.8	24.8
	75.2 (24)	5.1	14.9
	82.4 (28)	3.9	8.7
	89.6 (32)	3.5	8.6
Minute pirate bug[2]	70.0 (21.1)		26.4
	77.9 (25.5)	3-5	14.4
	92.0 (33.3)		8.4
	68.0 (20)	6.0	17.1
	77.0 (25)	3.8	14.7
	86.0 (30)	3.0	11.8
	95.0 (35)	2.5	9.9

[1] From Isenhour and Yeargan (1981); fed eggs of tobacco budworm (frozen for one hour prior to feeding) and water.

[2] From Askari and Stern (1972); fed Pacific spider mites, *Tetranychus pacificus* McGregor, and lima beans. Also from Butler (1966b); fed green beans or alfalfa leaves and alfalfa leaves infested with twospotted spider mites, *Tetranychus urticae* Koch.

developmental period at 75.2F (24C) from oviposition to adult eclosion for the insidious flower bug fed frozen tobacco budworm eggs and water was 20 days and as short as 12 days at 84.4 (28C) and 89.6 (32C) (Isenhour and Yeargan, 1981). Using a similar temperature [77F (25C) or 77.9 (25.5C)] but with different food (Pacific spider mites, *Tetranychus pacificus* McGregor or twospotted spider mites, *Tetranychus urticae* Koch), Askari and Stern (1972) and Butler (1966b) reported that development from the egg to the adult took about 18.5 days for the minute pirate bug. The insidious flower bug requires slightly longer to complete development than the minute pirate bug (Isenhour and Yeargan, 1981). Kiman and Yeargan (1985) evaluated the effect of several diets made up singly or of different combinations of frozen tobacco budworm eggs, maple pollen, green beans, adult soybean thrips, *Sericothrips variabilis* (Beach), or twospotted spider mites with free water on insidious flower bug and found that diets that included tobacco budworm eggs alone or in combination were optimum for survival, developmental time, longevity and fecundity. Also, survival to the adult stage was possible with all the diets except green beans and water alone. The ability of the insidious flower bug to complete development on different types of prey (moth eggs, mites and thrips) and on pollen alone is important. Evaluations with the minute pirate bug indicate that it is able to complete development on green beans alone and on pollen and water (Salas-Aguilar and Ehler, 1977). It is very significant that both species can complete development on a diet of pollen and water alone.

The preoviposition period for adult females is two to five days for both species. Laboratory studies indicate an adult longevity of about one month. Average fecundity for females fed optimum diets is about 100 eggs per female. Barber (1936) reported that female insidious flower bug feeding on bollworm eggs oviposited an average of 114 eggs each while Kiman and Yeargan (1985) found that females reared on diets containing tobacco budworms eggs oviposited 102 to 106 eggs per female. For the minute pirate bug, Askari and Sterns (1972) found an average fecundity of 129 eggs per female on a diet of Pacific spider mites and lima beans. However, Salas-Aguilar and Ehler (1977) reported an average fecundity of 59.6 eggs per female and a total longevity of 15.4 days on a diet of beans, pollen, thrips and free water.

Iglinsky and Rainwater (1950) suggested that the insidious flower bug is more likely to overwinter as a mature, mated female. Whitcomb and Bell (1964) reported that this species overwinters in the adult stage in plants such as wheat, alfalfa, grasses, mullein and henbit and become active on warm days. Kingsley and Harrington (1982) verified that insidious flower bug adults undergo a facultative reproductive diapause which is apparently terminated by favorable conditions during the spring, but that does not require an interval of cold exposure for diapause development. They also reported that the females mated before overwintering.

Major concerns relative to the importance of *Orius* spp. (flower bugs) as predators in cotton are timing of colonization, sources of colonizers during the season, ability to become established and reproduce in cotton and predatory efficacy. Flower bugs are early season colonizers of cotton and apparently are attracted by thrips and spider mites which develop during the early season (van den Bosch and Hagen, 1966;

Bohmfalk *et al.*, 1983; Smith and Stadelbacher, 1978). The sources for these early colonizers are likely winter crops and weeds. A major source of colonizer *Orius* spp., specifically the insidious flower bug may be field corn. The insidious flower bug has an affinity for silking corn and is able to reproduce very effectively in this crop while feeding on pollen and noctuid eggs (Quaintance and Brues, 1905; Barber, 1936). Movement of the insidious flower bug from corn to cotton occurs during mid-season after the corn is mature, and when bollworms also move from corn to cotton. High mortality as a consequence of insecticide applications may reduce the potential value of this predator at this time because it appears to be very susceptible to commonly used insecticides. The minute pirate bug and insidious flower bug apparently have the greatest impact in early to mid-season (Wene and Sheets, 1962, Smith and Stadelbacher, 1978).

Both species are important predators of thrips, mites, aphids, whiteflies and especially of eggs and small larvae of noctuids and other moth species in cotton (Ewing and Ivy, 1943; Fletcher and Thomas, 1943; Iglisky and Rainwater, 1950; Whitcomb and Bell, 1964; Bell and Whitcomb, 1964; van den Bosch and Hagen, 1966; Whitcomb, 1967; Ehler *et al.*, 1973; Ridgway and Lingren, 1972; McDaniel *et al.*, 1981; McDaniel and Sterling, 1982). Fletcher and Thomas (1943) identified insidious flower bugs as having preyed on the greatest percentage of bollworm eggs and larvae on cotton. McDaniel *et al.* (1981) and McDaniel and Sterling (1982) detected radioactive insidious flower bug nymphs and adults that had fed on radioactive eggs and first and second instars of bollworm/tobacco budworm placed in cotton. Adults of insidious flower bug consumed a mean of 0.7 and 4.4 eggs and first instar bollworms per predator per day, respectively, in laboratory studies (Lingren *et al.*, 1968). In California, the minute pirate bug is an important part of the natural enemy complex influencing bollworm, cabbage looper, and beet armyworm abundance in cotton (Ehler *et al.*, 1973; Eveleens *et al.*, 1973; van den Bosch and Hagen, 1966). As predators of the pink bollworm, the minute pirate bug preferred first instars over eggs (Henneberry and Clayton, 1985; Orphanides *et al.*, 1971).

Factors that may impact on the ability of flower bugs to colonize cotton involve the interaction between the cotton plant, prey available on the plant and the predator itself. Significant reductions in the numbers of insidious flower bug were found in nectariless and pilose cotton compared to more typical cotton varieties (Schuster *et al.*, 1976; Shepard *et al.*, 1972). Higher numbers of flower bugs were closely associated with higher numbers of mites and thrips (Yokoyama, 1978; Stoltz and Stern, 1978; Gonzalez and Wilson, 1982) on cotton plants in the San Joaquin Valley. The highest proportion of minute pirate bug nymphs was found on fruit during peak squaring. Adults were found higher on the plant than the nymphs, and there was a predominance of this species close to the plant terminal (Wilson and Gutierrez, 1980).

Ants—Although many predators feed on bollworms, tobacco budworms and cotton fleahoppers, ants, specifically fire ants, *Solenopsis* spp., are the only ant predators in cotton fields that play a significant role in the suppression of these key pests included in the TEXCIM model (Hartstack and Sterling, 1989; Hartstack *et al.*, 1990). Fire ants are also important predators of the cotton leafworm (Gravena and Sterling, 1983). Other predator groups such as green lacewings may be important predators of both bollworm/tobacco budworm and/or cotton fleahoppers but not boll weevils. For the characteristics needed for identification of the species of *Solenopsis*, see Hung *et al.* (1977).

The red imported fire ant, *Solenopsis invicta*, appears to be the most important species of fire ants in cotton agroecosystems of the United States because of its distribution, abundance and predatory aggressiveness. It is currently distributed over the southeastern United States from North Carolina to central Texas (Vinson and Sorensen, 1986) which constitutes a large portion of the Cotton Belt. Its geographical distribution is thought to be limited primarily by physical factors (Lofgren *et al.*, 1975). To the north it is limited by the zero degree Fahrenheit isotherm (Pimm and Bartell, 1980) and to the west by dry, desert conditions (Tschinkel, 1982). Red imported fire ants can become very abundant under certain conditions, approaching 2500 small colonies per hectare (Lofgren *et al.*, 1975).

The black imported fire ant, *Solenopsis richteri* Forel, is currently found only in northeast Mississippi and northwest Alabama, but may ultimately spread into northern Arkansas, Georgia and southern Tennessee (Vinson and Sorenson, 1986). Little is known of its predatory impact on the pests of cotton.

The tropical fire ant, *Solenopsis geminata* (F.), occupies a geographical distribution in the United States ranging from Texas to South Carolina along coastal regions. It is probably the most common fire ant species in the Rio Grande Valley of South Texas and into Mexico. Its biology is similar to the red imported fire ant (Vinson and Greenberg, 1986).

The last fire ant to be considered here is the southern fire ant, *Solenopsis xyloni* McCook, which can be found inland from California to North Carolina (Vinson and Greenberg, 1986). Where the mound of the other species tends to be elevated, the southern fire ant mound is flat.

Individuals of these four species of ants are considered to have an equal impact as predators of plant-feeding insects in cotton fields to simplify assessment. Thus, a tropical fire ant worker is considered to be equal to a red imported fire ant worker as a predator of cotton fleahoppers, bollworms/tobacco budworms or boll weevils. However, as a species, the red imported fire ant likely has a much greater impact on plant feeding insects in cotton than the other three species. Also, in areas occupied by the red imported fire ant, the other species have largely been displaced (Hung *et al.*, 1977).

The *Solenopsis* species are lumped into a group referred to as "fire ants" during the remainder of this paper. However, there is a paucity of information of the predatory impact of the species other than the red imported fire ant. It safely can be assumed that there are some differences in the biologies and predatory impacts of the species; however, until the importance of these differences are clear, an assumption of similarity is made. Even within a species, there may be differences between colonies. Some of the red imported fire ant colonies have multiple queens and some have single queens. The worker ants from a single queen colony forage out and back into the same mound. Worker ants from multiple queen colonies may forage out of one mound into a second mound which functions as a "supercolony" (Bhatkar, 1988). A major difference is that single queen colonies vary in density from 15 to 80 mounds per acre compared to 130 to 500 mounds per acre with multiple queen colonies. This difference in behavior by ants from different colonies ultimately may prove to have an important impact on the efficacy of ants as predators.

The biology and ecology of red imported fire ants has been reviewed by Lofgren *et al.* (1975), Lofgren (1986), and Vinson and Greenberg (1986). One of the main ways that fire ants disperse is through mating flights. Since these ants select locations for mound building that will be exposed to sunlight (Bhatkar, 1989), such as crop land and pastures, they quickly colonize and occupy recently planted cotton fields. Colonization of a cotton field takes place through the foraging of workers from colonies outside the cotton field and from new queens after a mating flight. Mated queens may fly up to 12 miles (Banks *et al.*, 1973) or more than 20 miles (Wojcik, 1983) and thus, can easily colonize large cotton fields rapidly. However, new queens produce only mini (very small) workers (Fincher and Lund, 1967) which are unlikely to have a major impact as predators of cotton pests. More than a month may be required before a newly colonized queen will begin to produce the minor workers needed for predation of pests. The worker ants that colonize cotton fields from established colonies outside the cotton field consist of minor and major workers that readily attack and kill cotton fleahoppers, bollworm/tobacco budworm and boll weevils (Hartstack and Sterling, 1989). Colonization of cotton fields by old colonies is triggered by several factors including the attraction of worker ants to aphid honeydew (Nielsson *et al.*, 1971), and cotton plant nectar (Agnew *et al.*, 1982). However, its primary diet and attractant consists of insects and other small invertebrates (Wilson and Oliver, 1969).

Though fire ants are polyphagous (feed on many kinds of food) predators, they do not pauperize the entire predator and parasite arthropod populations of cotton fields (Sterling *et al.*, 1979). Of course, ants can kill individuals of many species of natural enemies such as the parasites *Cardiochiles nigriceps* (Lopez, 1982) and *Bracon mellitor* Say (Sturm, 1989; Sturm and Sterling, 1990), and predaceous ground beetles (Brown and Goyer, 1982). Though these statements may seem contradictory (Lofgren, 1986), there is a distinct difference between "pauperizing a fauna (animal life inhabiting a specific environment)" and killing some individuals of a species. To pauperize a fauna, certain species are either eliminated or dramatically reduced in abundance due to some factor. To be able to claim that ants have a major impact on a species of parasite or predator, detailed life tables of the parasite or predator that clearly show the impact of ants are necessary. There should be clear evidence of indispensable mortality (Southwood, 1978) due to the ants on the parasites, similar to that shown for ants on boll weevils by Sturm *et al.*, (1989). Another source of convincing evidence of the impact of a natural enemy is produced by models such as TEXCIM that can predict the dynamics of pests based on counts of natural enemies (Sterling *et al.*, 1993).

Cotton Fleahoppers. Breene *et al.* (1990), in laboratory studies demonstrated the importance of the red imported fire ant as a predator of the cotton fleahopper. The predation rate was described as a function of both ant and cotton fleahopper abundance. At the highest ant density, 100 percent of the fleahoppers were killed in 24 hours. Field evidence of predation on fleahoppers by these ants is provided by Breene *et al.* (1988, 1989a) who found radiolabeled ants after field releases of radiolabeled fleahoppers. This predation takes place primarily at night so that it is infrequently observed during the day under field conditions.

Bollworm/Tobacco Budworm. Radiolabeled bollworm/tobacco budworm eggs and larvae were released in East Texas and the imported fire ant was shown to be a key predator of eggs (McDaniel and Sterling, 1979, 1982) and larvae (McDaniel *et al.*, 1981) (Plate 3-12). The rate of egg predation by ants is partially a function of temperature (Agnew and Sterling, 1982).

Boll Weevils. Fire ants are the only key predators of immature boll weevils (Sterling, 1978; Sterling *et al.*, 1984). These ants primarily attack immature boll weevils while they are feeding inside squares (flower buds) (Sturm and Sterling, 1986). They also attack immatures and soft adults in pupal cells when a boll splits at maturation (Agnew and Sterling, 1981). The hard exoskeleton of the adult boll weevil provides an excellent defense against ant predation so the impact of ants on adult weevils is minimal. The limitations of predation by fire ants is that they generally do not enter green squares on the plant nor do they enter green bolls before they split in search of boll weevils. However, after the square has dropped to the soil surface and has begun to decompose, ants readily chew a hole, enter and kill the weevil inside (Sturm, 1989; Sturm and Sterling, 1986; Sturm *et al.*, 1989, 1990).

In Texas, the rate of predation on cohorts of boll weevils ranges from 0 percent in western Texas where fire ants are absent to 100 percent in fields of eastern Texas where ants are abundant (Fillman and Sterling, 1983; Sturm and Sterling, 1990; Sturm *et al.*, 1989). The red imported fire ant is a major boll weevil mortality agent in East Texas and has its greatest impact during August (Sturm and Sterling, 1990; Sturm *et al.*, 1990). These ants are not equally abundant from field to field, thus cannot automatically be depended on for weevil control. However, in fields where they are abundant, cotton can be grown without insecticidal control of boll weevils, especially if delayed planting and early stalk destruction practices are employed (Sturm *et al.*, 1990). During an eleven year period, higher average yields were obtained in unsprayed plots containing ants than in plots where insecticides were used to control cotton pests (Sterling *et al.*, 1984). Ant predation was a key mortality factor of the boll weevil in eastern coastal regions of Texas (Fillman and Sterling, 1983; Sturm *et al.*, 1990). A density of 0.4 ants per plant was sufficient to control boll weevils 90 percent of the time (Fillman and Sterling, 1985). The removal of ants from cotton fields resulted in the resurgence of boll weevils compared to fields where ants were undisturbed (Sterling, 1984; Sterling *et al.*, 1989).

Fire ants are one of the ten groups of predators used by TEXCIM (Sterling *et al.*, 1993) to predict the phenology and abundance of pests in cotton. This model uses field counts of these ten groups of predators to forecast the abundance and economics of bollworms, tobacco budworms, cotton fleahoppers, and boll weevils and their multipest economics. The TEXCIM model (Sterling *et al.*, 1993) can be used to forecast the economic benefits of ant predation and the desiccation of boll weevil larvae in abscised (fallen) squares as well as the cost of boll weevil injury. This model is based on a detailed understanding of the biology and ecology of the boll weevil, its interaction with the cotton plant, and its interaction with other herbivorous (plant-eating) species and natural enemies.

Although fire ants sting humans, damage some crops, and short out electrical systems (Lofgren *et al.*, 1975; Lofgren, 1986; Vinson and Sorensen, 1986), they also are important natural enemies of some very important pests such as boll weevils, bollworms, tobacco budworms, fleahoppers, ticks, and sugarcane borers (Sterling *et al.*, 1979). Thus, it is not accurate to label fire ants as either pests or beneficial insects without qualification because under some conditions they cause more harm than good while in others, such as in cotton fields, they may make a profitable contribution. Fire ants can be "beneficial or harmful to the same plant or animal species depending on the time of year and/or developmental stage of the species, environmental conditions, or the status of the ant colony itself" (Lofgren, 1986).

SPIDERS

The ecological role of spiders in the suppression of cotton pests has been the subject of debate in the face of a large shortage of data. The theory of spiders as biological control agents has been dealt with by Riechert and Lockley (1984) who have expressed concern that biological control efforts have been more concerned with "putting out fires" rather than preventing them. They conclude that no single spider species can hold a prey in check and that even an assemblage of spider species can have little more than a "buffering effect". The argument prevails that spiders are generalist predators and do not form a tight linkage (i.e., prey specificity) in a density-dependent fashion with any particular prey species. Data by Nentwig (1986) however, contradict this notion since he found several species that were prey specialists. Most spiders have only about one generation per year, and have no way of increasing their numbers in response to prey density by local reproduction (Turnbull, 1973). However, spiders may respond to increased prey density by shrinking their searching territories, by recruitment and by colonization (Goodenough *et al.*, 1986). Thus, it generally has been concluded that spiders can maintain prey at low densities but they are largely incapable of reducing the abundance of outbreaks. We think that this conclusion tends to overgeneralize and that, until the true role of more spider species is known, it is premature to come to conclusions about spiders as a group. There is evidence that some spiders when operating in conjunction with other mortality factors, can not only maintain low prey populations but can also suppress them below economically damaging levels. Spiders have played a role in the reduction of crop damage in apple orchards (Mansour *et al.*, 1980), in sorghum (Horner, 1972; Muniappan and Chada, 1970a), and in rice (Kiritani *et al.*, 1972; Kiritani and Kakiya, 1975).

The evidence that spiders play a role in the dynamics of pest species in the cotton ecosystem is still patchy and far from complete. There is an abundance of studies in other agroecosystems as reviewed by Nyffeler (1982) and Nyffeler and Benz (1987). A considerable body of work dealing with the identification or feeding ecology of spider inhabitants of cotton fields is available (Dean and Sterling 1987; Lockley and Young, 1987; Nyffeler *et al.*, 1986, 1987a, b, c, 1988, 1989; Whitcomb and Bell, 1964; Young and Lockley, 1985, 1986). Whitcomb and Bell (1964) identified 160 species of spiders in Arkansas cotton fields while Dean *et al.*, (1982) identified 97 species in East Texas and Leigh and Hunter (1969) found 34 species in California and Skinner (1974) observed 154 species in Alabama and Mississippi cotton fields. Young and Edwards (1990) listed 308 species found on cotton in the United States. Many species found in cotton fields are only temporary residents. However, other species frequently are found in fairly large numbers and over broad geographical areas. Dean and Sterling (1987) observed that crab spiders, *Misumenops* spp., striped lynx spiders, *Oxyopes salticus* Hentz, and long-jawed orb weavers, *Tetragnatha laboriosa* Hentz were among the most abundant taxa of spiders in cotton throughout Texas. In general, about half of the predaceous arthropods in cotton are spiders (Fuchs and Harding, 1976). Because of the number of species of spiders considered important in cotton, it is only possible here to present a general review of the group and to cite sources where more specific information can be obtained. Roth (1993) provides keys and taxonomic differences for the identification of spider species found in the United States. Breene *et al.* (1993) discuss the biology, predation ecology, and significance of the 146 spider species collected from cotton in Texas and include a key and illustrations of the spiders.

The studies that have been conducted are important to our understanding of spider dynamics and feeding habits, but provide limited evidence of spider impact on key pests of cotton. Dean and Sterling (1987) reported that overall, spiders may have a positive or negative effect depending on whether they are feeding primarily on pests or other predators.

Cotton Fleahoppers. Twenty-two spider species are known to prey on the cotton fleahopper (Dean *et al.*, 1987). Though some insect predators prey on fleahoppers, spiders apparently play a dominant role in suppression of the cotton fleahopper (Breene *et al.*, 1989b). However, some of these species are of much greater importance than others. The studies of Dean *et al.* (1987), Breene and Sterling (1988) and Breene *et al.* (1988, 1989a, b, 1990) indicate the most important spider predators of the cotton fleahopper in Texas (Table 4).

The striped lynx spider generally constitutes the most important predator of the cotton fleahopper (Plate 3-13). In East Texas, the striped lynx spider comprised 23 percent of all spiders collected in cotton (Dean *et al.*, 1982) and was abundant throughout Texas (Dean and Sterling, 1987). It also dominates in soybean and cotton ecosystems in Mississippi (Pitre *et al.*, 1978). The striped lynx spider has a somewhat limited prey range and apparently shows some preference for members of the Heteroptera and Homoptera because 71 percent of its prey items belong to these orders (Lockley and Young, 1987). This spider is an active leaper and can be recognized by eight eyes in

Table 4. Spider predators of the cotton fleahopper in Texas.[1]

Groups (Family) and Species	Index of efficacy for fleahoppers	
	Nymphs	Adults
Jumping spiders (Salticidae)	0.9	0.9
Metaphidippus galathea		
Hentzia palmarum		
Phidippus audax (black and white jumping spider)		
Lynx spiders (Oxyopidae)	0.7	0.7
Oxyopes salticus (striped lynx spider)		
Peucetia viridans (green lynx spider)		
Cheiracanthium inclusum (winter spider)		
Crab spiders (Thomisidae)	0.5	0.4
Misumenops celer (celer crab spider)		
Web spinning spiders	0.4	0.3
Grammonota texana		
Tetragnatha laboriosa (long-jawed orb weaver)		

[1] From Breene *et al.* (1989a) and Hartstack et al. (1991). A value of 1.0 would have the highest efficiency rating against the cotton fleahopper while a value of 0 would indicate no efficacy. The index values relate to the consumption rates of cotton fleahopper by these spider groups.

the form of a hexagon on the carapace (the top part of the head and thorax), large spines on the legs, and a black stripe on each of the chelicerae (first pair of appendages of the head that are used as jaws; they terminate with fangs that are used to help catch prey) and with four longitudinal gray bands on the carapace. The female averages 1/4th inch (5.9 millimeters) in length and the male, about 1/5th inch (4.7 millimeters). There are one to two generations per year. Other features of its biology are available from Whitcomb and Eason (1967). It is found in many habitats (including crops), but primarily in grassy areas; it is found throughout the Cotton Belt (Young and Lockley, 1985). Overwintering occurs in the second to seventh instar but adults can be found year-round in warmer areas. Dispersal, which is mostly accomplished by earlier instars, is achieved by ballooning, a method spiders use to "fly" through the air on a strand of silk from their spinnerets (located at the end of their abdomen).

The green lynx spider, *Peucetia viridans* (Hentz), which is found throughout the Cotton Belt, is one of the largest spiders in cotton fields and consumes large numbers of cotton fleahoppers (Nyffeler *et al.*, 1987a). Females average about 5/8ths inch (16.2 millimeters) in length and the males, about 1/2 inch (11.9 millimeters). The eyes and legs are similar to that for the striped lynx spider but the green lynx is green in color and is larger. There is one generation per year. Details of its life history are available from Whitcomb *et al.* (1966). It is usually the larger instars that move into cotton in June and July.

The winter spider, *Cheiracanthium inclusum* (Hentz), is not a true lynx spider but is placed in this group because it has a similar efficiency rating to the lynx spiders (Plate

3-14). It has one (possibly two) generation(s) per year and overwinters as a late instar or adult. Distinguishing characters include two rows of eyes, a lanceolate mark on the abdomen, and is cream colored to light brown (occasionally pale yellow to pale green). The female is about 9/32nds inch (7.2 millimeters) long and the male is 15/64ths inch (5.8 millimeters). It is nocturnal (active at night) and hides during the day in tube webs in the tips of rolled leaves or bracts of cotton fruit. It is widely distributed and feeds on a wide range of prey. Peck and Whitcomb (1970) studied the biology.

Crab spiders are ambush predators that sit and wait in the terminals of cotton plants (Plates 3-15 and 3-16). They are the most abundant taxa of spiders in the western part of Texas (Dean and Sterling, 1987). Muniappan and Chada (1970b) reported on the biology of *Misumenops celer* (Hentz). They can be recognized by their crab-like first two pairs of legs, which are the longest. The females are about 11/64ths to 17/64ths inch (4.4 to 6.7 millimeters) in length and the males are about 1/16th to 5/32nds inch (1.5 to 4.0 millimeters). There are one to two generations per year. They are found in many types of habitats and have a variable diet.

Jumping spiders (family Salticidae) prefer to attack prey with high activity levels and crawling velocities (Freed, 1984) (Plate 3-17). However, jumping spiders will also prey on sessile prey (prey that do not move about) such as bollworm eggs (McDaniel and Sterling, 1979, 1982). They have three rows of eyes with the eyes in front the largest. They have a compact rectangular body with stout legs. The size of the adult ranges from about 1/8th to 19/32nds inch (3 to 15 millimeters) in length depending on the species. The color varies greatly from light to iridescent to black with combinations of colors. There generally is one generation per year and they overwinter as late instars and adults. They are found in many habitats and are widespread across cotton growing areas.

Web spinners (families Araneidae and Tetragnathidae) vary greatly in color, size [5/64ths to 1 and 1/10th inches (2 to 28 millimeters) in length], and shape but all make some type of web (orb, tangled, or in-between) to capture various types of prey. More than two-thirds of all orb weavers in cotton in Texas consist of five species: star-bellied orb weaver, *Acanthepeira stellata* (Walckenaer); *Neoscona arabesca* (Walckenaer), *Gea heptagon* (Hentz); long-jawed orb weaver, *Tetragnatha laboriosa* Hentz; and, feather-legged spider, *Uloborus glomosus* (Walckenaer). More than 99 percent of their prey consists of insects, (mostly aphids) and less than 1 percent being spiders (Nyffeler *et al.*, 1989).

<u>Bollworm/Tobacco Budworm</u>. Spiders feed readily on bollworm/tobacco budworm eggs, larvae, and adults (McDaniel *et al.*, 1981; McDaniel and Sterling, 1982; Whitcomb, 1967). Their impact on these species is less certain than their impact on the cotton fleahopper and it depends on the abundance and efficacy of the various spider species (Hartstack and Sterling, 1989). Although most of the evidence of spider predation is on bollworm/tobacco budworm larvae, the green lynx spider has also been observed seizing bollworm and cotton leafworm moths (Whitcomb and Bell, 1964).

<u>Boll Weevils</u>. The impact of spiders on the boll weevil is limited to the reports of Whitcomb and Bell (1964) that the black and white jumping spider, *Phidippus audax*

(Hentz), has been observed feeding on an adult boll weevil in the field. They also observed spiders of the family Lycosidae including the wolf spiders *Gladicosa gulosa* Walckenaer, *Hogna punctulata* (Hentz) and *Varacosa avara* (Keyserling) feeding on boll weevil adults in the laboratory. However, there are other species capable of feeding on this pest. Black widow spiders, *Latrodectus mactans* (Fabricius), feed readily on the legs of beetles. These spiders have very small mouthparts so that they are only able to suck the body fluids of large prey through their legs. Also, the green lynx spider has been observed to feed on an adult boll weevil in the field (Breene *et al.*, 1993). However, there is currently no evidence that any spider species can kill immature boll weevils within the fruit.

<u>Other Cotton Insects</u>. Radiolabeled pink bollworm moths were killed by the following three spiders: wolf spider, *Pardosa milvina* (Hentz), jumping spider, *Plexippus paykulli* (Audouin), and black and white jumping spider according to Clark and Glick (1961). Thus, it is very likely that spiders also feed on other adults of cotton pests such as cotton leafworms. Nine spider species were observed to feed on pink bollworm larvae in southern California (Orphanides *et al.*, 1971). Eggs of the cotton leafworm are fed upon by green lynx spiders, winter spiders, gray dotted spiders, *Hibana (=Aysha) gracilis* (Hentz) and the orb weaver spider, *Neoscona arabesca* and first instar larvae were fed on by crab spiders, long-jawed orb weavers, gray dotted spiders, green lynx spiders, winter spiders, and the jumping spider, *Hentzia palmarum* (Hentz) and an erigonid (Gravena and Sterling, 1983). The cotton leafperforator, *Bucculatrix thurberiella* Busck, is attacked frequently by spiders of the genera *Theridion* and *Theridula* of the family Theridiidae which are commonly called comb-footed spiders, in cotton fields in northern Peru (Herrera and Alvarez, 1979). Spiders were able to suppress larval infestations of Egyptian cotton leafworm, *Spodoptera littoralis* (Boisduval), in Israel (Mansour, 1987).

Nyffeler (1982) has suggested that because spiders eat other predators that they do as much harm as good in cotton fields. If this is a valid criticism of spiders, then it also applies to many of the insect predators. Predaceous insects and spiders are generally polyphagous. In one sense, having a wide prey range is beneficial in that these predators can switch to other prey when a preferred prey becomes rare so that it is not necessary for them to leave the cotton field to prevent starvation (Murdoch, 1969).

ECONOMIC IMPACT OF PREDATORS

Using the TEXCIM model it is possible to retrospectively estimate the value of predators of cotton fleahoppers, boll weevils, or bollworms and tobacco budworms. An example (Table 5) shows values of fleahopper predators for five years in untreated cotton fields in East Texas. As a group, web spinning spiders had the greatest average economic impact [$1.78 per acre ($4.40 per hectare)] over the growing season. Lynx spiders [$1.47 ($3.63)] were next, followed by red imported fire ants [$1.06 ($2.62)], predaceous bugs [$0.40 ($.99)], crab spiders [$0.38 ($.94)] and jumping spiders [$0.34 ($0.84)].

Care must be exercised in interpreting these values. A farmer using no insecticides would make an average profit of $5.44 ($13.44 per hectare) more per acre with predators than without them. This does not mean that using predators is always more profitable than using insecticides for fleahopper control. It means that the value of predators must be taken into account when deciding whether to use insecticides if all costs and benefits are taken into consideration in making management decisions.

Table 5. Value ($) of predators of the cotton fleahopper for the indicated years.[1]

Predators	1978	1979	1980	1981	1989	Average
Fire ants	1.09	0.37	0.14	3.58	0.13	1.06
Lynx spiders	0.85	0.48	0.11	5.39	0.54	1.47
Jumping spiders	0.48	0.13	0.18	0.51	0.38	0.34
Crab spiders	0.66	0.08	0.11	0.34	0.71	0.38
Web spinning spiders	1.12	1.47	0.22	5.21	0.90	1.78
Predaceous bugs	0.48	0.08	0.10	0.47	0.87	0.40
Total	4.68	2.61	0.86	15.50	3.53	5.44

[1] From Sterling et al. (1992).

PARASITES

Although a number of parasite species associated with the cotton insect pest complex have been identified, the emphasis in our discussion is on important parasite species of bollworm/tobacco budworm. These pests are attacked by numerous species of wasp and fly parasites (Table 6). The most important wasp parasites, in terms of number of hosts parasitized, appear to be *Microplitis croceipes*, *Cardiochiles nigriceps* and *Trichogramma* spp. Some of the more important fly parasites are *Archytas marmoratus* and *Eucelatoria bryani*. These parasites will be discussed in the following pages.

WASPS

Microplitis croceipes—One of the most important wasp parasites of bollworm/tobacco budworm larvae is *Microplitis croceipes*, an endoparasitic (develops inside the host) braconid. This parasite is found from New Jersey to Georgia and west to New Mexico, Arizona, Utah and Oregon (Muesebeck *et al.*, 1951; Marsh, 1978). This parasite is common in Mississippi throughout the cotton growing season (Lewis and Brazzel, 1968) and is reported to be active over a longer period of time than any other parasite attacking *Helicoverpa/Heliothis* (Stadelbacher *et al.*, 1984). Apparently *Microplitis croceipes* does not occur in California (van den Bosch and Hagen, 1966). *Microplitis croceipes* attacks the bollworm, tobacco budworm and *Heliothis subflexa* (Guenee), and is among the most common and important parasites of bollworm/tobacco budworm larvae in the United States (Quaintance and Brues, 1905; Lewis and Brazzel, 1966, 1968; Snow *et al.*, 1966; Bottrell *et al.*, 1968; Neunzig, 1969; Lewis and Snow, 1971; Young and Price, 1975; Smith *et al.*, 1976b; Marsh, 1978; Danks *et al.*, 1979; Eger *et al.*, 1982; Powell and Elzen, 1989). It often

Table 6. List of representative parasites attacking bollworm/tobacco budworm in the United States.

Group	Family	Species
Wasps[1]:		
	Braconidae	
		Bracon platynotae (Cushman)
		Cardiochiles nigriceps (Vierick)
		Chelonus insularis (Cresson)
		Cotesia marginiventris (Cresson)
		Meteorus autographa Muesebeck
		Meteorus laphygmae Vierick
		Microplitis croceipes (Cresson)
		Microplitis feltiae Muesebeck
		Rogas perplexus Gahan
	Eulophidae	
		Euplectrus platyhypenae Howard
	Ichneumonidae	
		Campoletis flavicincta (Ashmead)
		Campoletis sonorensis (Cameron)
		Cryptus albitarsis (Cresson)
		Hyposoter annulipes (Cresson)
		Netelia sayi (Cushman)
		Netelia spinipes (Cushman)
		Pristomerus spinator (Fabricus)
	Scelionidae	
		Telenomus heliothidis Ashmead
	Trichogrammatidae	
		Trichogramma spp.
Flies[2]		
	Tachinidae	
		Archytas marmoratus (Townsend)
		Carcelia illota (Curran)
		Eucelatoria armigera (Coquillett)
		Eucelatoria bryani Sabrosky
		Euphorocera claripennis (Macquart)
		Euphorocera floridensis Townsend
		Euphorocera tachinomoides Townsend
		Gonia spp.
		Gymnochaetopsis fulvicauda (Walton)
		Hyphantrophaga hyphantriae (Townsend)
		Lespesia aletiae (Riley)
		Lespesia archippivora (Riley)

Table 6. Continued

Group	Family	Species
		Lespesia frenchii (Williston)
		Metaplagia occidentalis Coquillett
		Nemorilla pyste (Walker)
		Palexorista laxa (Curran)
		Voria aurifrons (Townsend)
		Winthemia quadripustulata (Fabricius)
		Winthemia rufopicta (Bigot)

[1] Data from Krombein et al. (1979).

[2] Data from Arnaud (1968).

parasitizes more than 50 percent of the individuals that survive to reach the larval stage in field populations (Mueller and Phillips, 1983; Stadelbacher *et al.*, 1984; King *et al.*, 1985). Mueller (1983) reported that, although *Microplits croceipes* females did not distinguish between bollworms, and tobacco budworms, parasite survival was higher in bollworms than in tobacco budworms.

Adult *Microplitis croceipes* are large dark brown to black wasps, with yellow to reddish abdomen (darker posteriorly) and legs (Plate 3-18). The wings are rather dark. The female has a short ovipositor and antennae that are shorter [about 5/32nds inch (4 millimeters)] than those of the male [about 15/64ths inch (6 millimeters)].

Microplitis croceipes has three larval instars (Lewis, 1970a). The egg hatches from 36 to 48 hours after oviposition. The first instar larval stage lasts for approximately four days, the second instar for about three days, and the third instar for about one day. The pupal stage inside the cocoon lasts for approximately six days, or the insect may remain in diapause, in the prepupal stage inside the cocoon for a variable period of time. Under field conditions, the cocoons are found underground in a tunnel excavated by the parasitized host larva. Prepupae are induced into diapause by low temperatures (Powell and Elzen, 1989). Diapause inducement at 59, 68 and 86F (15, 20, and 30C) was 100, 60 and zero percent, respectively. Short daylengths cause a higher rate of diapause induction with appropriate temperatures. It took an average of 9 to 11 days for fully developed parasite larvae to emerge from the host, depending on the developmental stage of the host at oviposition (Lewis, 1970b).

Although all bollworm and tobacco budworm (host) larval stages are subject to attack, *Microplitis croceipes* females preferentially attack third instar bollworm and tobacco budworm larvae (Lewis, 1970b; Hopper and King, 1984). First and second instar larvae are so small that they are difficult to find while fourth and fifth instars are so large that they can dismember the parasites with their mandibles (Herman and Morrison, 1980). Late fifth instar larvae (prepupae) are unsuitable as hosts and produce no parasites if they are accepted for oviposition (Lewis, 1970b). After parasitization, host larvae continue normal development to the fourth or fifth instar before the parasite larvae emerge. Hopper and King (1984) determined that bollworm/tobacco budworm larvae parasitized as second, third, and fourth instars moved less and damaged fewer squares, blooms, and bolls than unparasitized larvae.

Microplitis croceipes is very host specific. Bollworm/tobacco budworm larvae, however, attack numerous plant species. Thus, the role of plants in the host selection behavior of this parasite is very important. *Microplitis croceipes* has been reported to attack bollworm/tobacco budworm in many cultivated crops, including alfalfa, beans, cotton, tobacco, tomato, corn and sorghum (Bottrell *et al.*, 1968; Butler, 1958; Burleigh, 1975; Lewis and Brazzel, 1966; Neunzig, 1969; Shepard and Sterling, 1972a; Smith *et al.*, 1976b; Young and Price, 1975; Powell and King, 1984). Parasitization in corn and sorghum is extremely low (Lewis and Brazzel, 1968; Neunzig, 1969; Smith *et al.*, 1976b). Stadelbacher *et al.* (1984) report that *Microplitis croceipes* parasitized bollworm/tobacco budworm larvae on more species of plants, in Mississippi, than any other parasite.

Mueller (1983) studied the survival of *Microplitis croceipes* in nine host insect/plant combinations and found that survivorship was higher in host larvae that were reared on cotton than in hosts reared on either bean or tomato. Thus, the plant on which a larva feeds also can be an important factor in determining the probability of successful parasitism by this species. The availability of nectar on the cotton plant has been determined to affect the longevity and fecundity of the adult parasite (Calderon, 1977). Mean adult longevity was one day less and fecundity was reduced by 49 percent on nectariless cotton compared to nectaried cotton.

Contact with the frass (excrement plus chewed up/regurgitated plant material) of bollworm larvae results in an intense response by *Microplitis croceipes* females involving a thorough antennal examination of the surrounding substrate (Lewis and Jones, 1971). The most active component from bollworm larval frass is 13-methylhentriacontane, although the females also responded to several related chemicals (Jones *et al.*, 1971). The material on which the larva feeds has been shown to affect the response of *Microplitis croceipes* females to host frass. Frass from bollworm larvae fed on pink-eyed purple hull cowpea cotyledons was significantly more stimulatory than was frass from larvae reared on a modified pinto bean diet (Sauls *et al.*, 1979). Plants also influence the degree of stimulation of extracts of larval frass (Table 7).

Recent studies have clearly shown that learning or conditioning is an important component of the foraging behavior of *Microplitis croceipes* and other parasites (Drost *et al.*, 1986; 1987). For example, exposure of *Microplitis croceipes* females to bollworm larval frass immediately before release of the parasites, resulted in increased rates of parasitization in the greenhouse (27.6 percent for stimulated females versus 0.0 percent for unstimulated females) (Gross *et al.*, 1975). The increase in parasitization due to prerelease exposure to frass was caused by release of an intensive searching behavior and subsequent reduction of the tendency to disperse upon release. In a field study, 16 stimulated females remained to search potted crowder pea plants with only one dispersing, while 21 unstimulated females dispersed, leaving only one to search.

Microplitis croceipes are relatively tolerant of many of the insecticides used in cotton (King *et al.*, 1985c; Powell *et al.*, 1986; Bull *et al.*, 1987; Elzen *et al.*, 1987). Bull

Table 7. Average scored host selection response of *Microplitis croceipes* females to extracts of frass from larvae fed on different plants or cottonseed meal laboratory diet.[1,2]

Food source	Average host selection response[4]
Soybean	1.6a
Cotton	1.0b
Cottonseed meal[3]	0.3c
Corn	0.0c

[1] Means followed by different letters are significantly different ($P<0.05$) as determined by Duncan's multiple-range test.

[2] Data from Nordlund and Sauls (1981).

[3] Burton (1970).

[4] Responses were scored on a three point scale. When a parasite made an extensive examination of a treated spot with her antennae, exhibited considerable excitement, and occasionally probed with her ovipositor (positive response) on the first pass, a score of 3 was given. If a positive response was elicited on the second pass, a score of 2 was given, etc. When a parasite did not respond after three direct passes over the treated spot, a score of 0 was given (Lewis and Jones, 1971). Each replication consisted of the mean score of 10 parasites for each of the test materials.

et al. (1989) reviewed studies of the toxicity of insecticides to adults of this parasite and they identified the following general response pattern: (a) organophosphorus insecticides—highly susceptible to phosphorothionate-type chemicals, relatively tolerant of phosphates; (b) organochlorines—highly susceptible to cyclodienes, relatively tolerant of toxaphene, highly tolerant of DDT; (c) carbamates—tolerant of oxime-type compounds; (d) pyrethroids—highly tolerant. Elzen *et al.* (1989) found that the carbamate methomyl (Lannate®, Nudrin®) caused mortality significantly higher than a mixture of fenvalerate (Pydrin®) and chlordimeform (Galecron®, Fundal®) or the carbamate thiodicarb (Larvin®). The relatively high level of tolerance to certain insecticides which are highly effective against the tobacco budworm may be exploited in a management program that emphasizes conservation of natural enemies.

Cardiochiles nigriceps—Another widely distributed braconid, *Cardiochiles nigriceps*, is found from Washington D. C., south to Florida and west to Kansas, Texas and Mexico (Krombein *et al.*, 1979). It is one of the more important parasites of tobacco budworm larvae (Chamberlin and Tenhet, 1926; Grayson, 1944; Lewis and Brazzel, 1968; Neunzig, 1969; Johnson and Manley, 1983; Roach, 1975; Snow *et al.*, 1966; Smith *et al.*, 1976b). This species can successfully parasitize only tobacco budworm and *Heliothis subflexa* (Lewis *et al.*, 1967) and thus is even more host specific than *Microplitis croceipes*.

Adult *Cardiochiles nigriceps* are robust insects about 3/12ths inch (7 millimeters) long with antennae that are approximately 15/64ths inch (6 millimeters) long (Plate 3-19). The adult insect is black with a red abdomen, most of the hind and lower mid-legs are also red. The antennae are black and the wings are very dark. The ovipositor is short and black and often concealed (Danks *et al.*, 1979). *Cardiochiles nigriceps* is easily recognized in the field, once the observer is familiar with this insect. The egg and three larval instars are described by Lewis and Vinson (1968).

Cardiochiles nigriceps overwinters in the soil as a prepupa in a cocoon (Danks *et al.*, 1979; Lopez, 1982). Overwintering adults emerge in May in North and South Carolina, April and June in Mississippi, April in Florida, and early June in central Texas (Chamberlin and Tehnet, 1926; Lewis and Brazzel, 1968; Roach, 1975; Danks *et al.*, 1979; Lopez, 1982). There is the potential for overwintering emergence to occur throughout the summer in Central Texas (Lopez, 1982).

Female *Cardiochiles nigriceps* attacked and parasitized all five tobacco budworm larval instars in the field (Lewis and Brazzel, 1966). However, late second and early third instar hosts are preferred (Vinson, 1972).

The rates of parasite development in the various host instars are the same. Small host larvae (first and second instars) continue to grow to the fourth or fifth instar after parasitization while those already in the fourth or fifth instar when parasitized grow very little (Lewis and Brazzel, 1966). The time from oviposition to emergence of a fully developed parasite larva ranged from 11 to 17 days at 80F (26.7C) with most of them completing their development in 13 to 15 days (Lewis and Brazzel, 1966). Developmental times of the egg to larval and prepupal-pupal stages of *Cardiochiles nigriceps* at different constant temperatures are given in Table 8. These results are similar to those reported by Chamberlin and Tenhet (1926). The longevity of adults is temperature dependent (Table 9) and with adults remaining active for approximately two weeks (Vinson *et al.*, 1973).

Table 8. Average duration in days of egg-larval and prepupal-pupal stages of the parasite, *Cardiochiles nigriceps*, at different constant temperatures.[1]

	Average number of days	
Temperature F (C)	Egg-larval stage	Prepupal-pupal stage
62.6 (17.0)[2]	45.1	—
68.0 (20.0)[2]	28.4	—
72.5 (22.5)	19.2	23.0
77.0 (25.0)	14.8	19.3
82.0 (27.8)	11.9	14.8
86.0 (30.0)	10.7	12.8
90.5 (32.5)	9.3	12.2
95.0 (35.0)	9.6	14.8

[1] Data from Butler et al. (1983).

[2] At constant temperatures below 77F (25C), the insects stayed in diapause.

Table 9. Mean longevity in days of males and females of the parasite, *Cardiochiles nigriceps,* at different constant temperatures.[1]

Temperature F(C)	Average number of days	
	Males	Females
68 (20.0	25.6	22.6
73 (22.5)	31.5	30.9
77 (25.0)	19.7	20.2
82 (27.8)	16.3	16.6
86 (30.0)	10.7	9.4
91 (32.5)	15.0	12.9
95 (35.0)	8.0	6.4

[1] Data from Butler et al. (1983).

Cardiochiles nigriceps females will attack both bollworm and tobacco budworm larvae, but no progeny develop in bollworm (Lewis and Brazzel, 1966). *Heliothis subflexa* is also a suitable host while *Heliothis phloxiphaga* Grote and Robinson is unsuitable (Lewis *et al.*, 1967; Lewis and Vinson, 1971). *Cardiochiles nigriceps* eggs or first instar larvae are encapsulated by hemocytes (blood cells in the body cavity of insects) in bollworm larvae (Lewis and Vinson, 1968; Vinson, 1968a). Poison gland material and calyx fluid act synergistically to regulate growth of parasitized tobacco budworm larvae (Guillot and Vinson, 1972).

The host selection behavior of *Cardiochiles nigriceps* females involves responses to a number of semiochemicals. The females are known to be attracted to a number of plants in the field including tobacco (Vinson, 1975), devil's claw [unicorn plant, *Probosidea louisianica* (Mill.) Thellung], and pigeon pea, *Cajanus cajan* L. (personal observation), at least at certain stages in the plants' phenology. Females of *Cardiochiles nigriceps* locate hosts that are hidden from view by responding to a kairomone in the salivary secretion of tobacco budworm larvae which is perceived on contact with the salivary secretion (Vinson and Lewis, 1965; Vinson, 1968b). This kairomone (chemical that elicits a response from the receiving insect) consists of three long-chain hydrocarbons (11-methyl-hentriacontane, 16-methyl-dotriacontane and 13-methyl-hentriacontane) (Vinson *et al.*, 1975). A trail of this material is followed by a female parasite, provided that she is in the proper physiological state. No response is elicited by fecal material or extracts of cuticle, while hemolymph (blood-like circulatory fluid in insects) elicits a negative "flight" response (Vinson and Lewis, 1965).

The response of *Cardiochiles nigriceps* females to the presence of tobacco budworm larval mandibular gland (gland that is on, near or associated with the insect's mouth) kairomone was studied in detail by Strand and Vinson (1982). The female walks in a relatively straight path prior to contacting a kairomone patch (area on a surface with a concentration of kairomone sources). Upon contacting the patch, however, the female stops walking, antennates the patch surface (i.e., searches the patch surface with its antennae), and then enters the patch. In the patch, the parasite's movement is accelerated and there is a much higher rate of turning than is exhibited prior to entering the patch. When the parasite encounters an edge, it usually will turn sharply back into the patch. Thus, the patch is thoroughly searched for any larvae that might be present.

Cardiochiles nigriceps females also are able to discriminate against previously searched substrates on which first instar larvae had been feeding and against larvae that had previously been parasitized (Vinson, 1972). First instars are small and the female often makes numerous ovipositor thrusts before successfully ovipositing in the host. The ovipositor thrusting may result in deposition of an epideictic pheromone on the substrate allowing discrimination against the patch. The Dufour's gland (a gland associated with the sting or oviposition) has been identified as the source of a hydrocarbon that mediates host discrimination by *Cardiochiles nigriceps* (Vinson and Guillot, 1972; Guillot *et al.*, 1974).

Trichogramma spp.—The minute wasps of the genus *Trichogramma* have a worldwide distribution and include over 90 nominal forms (Hung *et al.*, 1985) (Plate 3-20). These wasps are parasitic on the eggs of other insects, primarily Lepidoptera, and they are the most extensively used parasite or predator for periodic release programs in the world, with commercial utilization in ten countries (Ridgway and Morrison, 1985). On a worldwide basis, the three most commonly used species of *Trichogramma* are *Trichogramma dendrolimi* Matsumura in China (Li, 1982), *Trichogramma evanescens* Westwood (Sens. Lat.) in Europe (Hassan, 1982; Voegele, 1981; Voronin and Grinberg, 1981) and *Trichogramma pretiosum* Riley in the United States (Ridgway *et al.*, 1981).

The biosystematics of these minute wasps are not fully known, at least in part because of their small size. *Trichogramma evanescens* for example was recently divided into two species: *Trichogramma evanescens* and *Trichogramma maidis* Pintureau and Voegele (Pintureau and Voegele, 1980). Thorpe (1984) found 14 biparental and one uniparental species of *Trichogramma* in a 4,842 square feet (450 square meters) plot of weedy vegetation. Some of the more recent taxonomic treatments of the genus are Nagarkatti and Nagaraja (1971, 1977) and Pinto and Oatman (1985).

Trichogramma exiguum Pinto and Platner and *Trichogramma pretiosum* were the two most common native species in Portland, Arkansas; Clinton, North Carolina (Hung *et al.* 1985) and in Central Texas (López *et al.*, 1982). *Trichogramma exiguum* has a yellow head marked with transverse lines above the antennal sockets. The thorax and pronotum have brown spots on each side. The brown coloration is more extensive in the male. The exact range of *Trichogramma exiguum* is unknown, but it is found in Alabama, Arkansas, Missouri, Texas and probably as far south as Peru (Pinto *et al.*, 1978; López *et al.*, 1982; Hung *et al.* 1985). *Trichogramma pretiosum* has a yellow head and thorax. The thorax is suffused with brown laterally (i.e., a brown coloring with streaking on the sides of the thorax). The legs are light yellow, marked with dark brown on the dorsum (the back or top side) of the femora (third leg segment located between the trochanter and the tibia) and tarsi (the part of the leg beyond the tibia, consisting of one or more segments). The abdomen is yellow brown, darker medially at the posterior. This species is found throughout southern Canada and the United States, except the most southern and southwestern areas, and south to Colombia, South America (Pinto *et al.*, 1978; Krombein *et al.*, 1979). Both of these species are found in campestral (fields or open country) habitats.

The first appearance of *Trichogramma pretiosum* in the spring corresponds approximately with the first general occurrence of bollworm eggs on corn (Quaintance and Brues, 1905). In a study conducted in Central Texas, Lopez *et al.* (1982) found *Trichogramma* parasitizing corn earworm or bollworm eggs in corn from the middle of May until the corn matured. The species involved were *Trichogramma exiguum* (69.6 percent), *Trichogramma pretiosum* (20.9 percent), *Trichogramma maltbyi* Nagaraja and Nagarkatti (6.1 percent) and *Trichogramma minutum* Riley (3.4 percent). In cotton, *Trichogramma pretiosum* was the most common species (78.3 percent) and it was active through the middle of September. In regrowth grain sorghum in September and October, *Trichogramma exiguum* was again dominant (71.7 percent). The study shows that *Trichogramma exiguum* and *Trichogramma pretiosum* are active throughout the growing season. The generation time for *Trichogramma pretiosum* is eleven days in May, decreasing to eight days in July and August and lengthening to eleven days by the beginning of October (Quaitance and Brues, 1905). Lepidopterous eggs parasitized by *Trichogramma* turn dusky black in color a few days after being parasitized and observation of an accummulation of black eggs on cotton plants in the field indicates a high level of parasitization by these parasites.

There is considerable difference in the longevity estimates for *Trichogramma* in the literature Quaintance and Brues (1905) found that *Trichogramma pretiosum* adults live at most four days witn an average life span of one and a half days. Orphanides and Gonzalez (1971) found that mean longevity varied from 16.8 days to 20.6 days with varying host densities at 77F (25C), 80 percent relative humidity and a 13 hour photophase. Nordlund et al. (1976) found that the average adult longevity of *Trichogramma pretiosum* females reared on bollworm/tobacco budworm eggs at 78.8F (26C) and 70 percent relative humidity and provided honey water, was 10.6 days for females that were not in contact with moth scale extract and 12.2 days for females in contact with this material. Some of the females lived as long as 24 days. Keller and Lewis (1985) found that the longevity of *Trichogramma pretiosum,* which had been reared on *Sitotroga cerealella* (Olivier) eggs, conditioned for release (Bouse and Morrison 1985) and held at ambient conditions in the field, varied between 0.9 and 3.8 days.

Trichogramma pretiosum and *Trichogramma exiguum* overwinter in the immature stages inside the host egg. Adults emerge during warm winter periods and are active at relatively low temperatures. Apparently, diapause is not involved and the decrease in developmental rate is primarily due to the lower winter temperatures (Lopez and Morrison, 1980; Keller, 1986). Keller (1986) reported that prolonged adult longevity of *Trichogramma exiguum* due to low temperatures during the winter also contributes to the overwintering of that species. Mild fall temperatures may have a considerable impact on overwintering populations because parasitization of host eggs occurs relatively late in the fall when host eggs are scarce.

Trichogramma pretiosum was the only parasite reared from bollworm eggs collected from sweet corn in southern California during a three year study (1963 to 1965) (Oatman, 1966). An average of 2.1 *Trichogramma* emerged per bollworm egg. Parasitization rates ranged from 0 to 100 percent. Parasitization was generally higher on sweet corn maturing during the middle of the season (August) than on plantings that matured earlier or later. *Trichogramma pretiosum* can be used to control cabbage looper, and tobacco hornworm, Manduca sexta (L.), in California tomatoes (Oatman and Platner, 1971).

Semiochemicals play important roles in the host selection behavior of *Trichogramma. Trichogramma evanescens* responds to kairomones left by adult moths (Laing, 1937). Chemicals in bollworm moth scales can be used to increase the rate of parasitization by *Trichogramma evanescens* (Jones et al., 1973; Lewis *et al.*, 1975). Bollworm moth scales stimulate an intensive host location behavior in *Trichogramma pretiosum* and treatment pattern is important (Lewis *et al.*, 1979, Beevers et al., 1981).

Semiochemicals from plants are also important. Altieri *et al.* (1981) found that water extracts of *Amaranthus* spp. (pigweeds) and corn significantly increased parasitization of bollworm by naturally-occurring *Trichogramma* spp. and released *Trichogramma pretiosum* in soybean fields. *Trichogramma* spp. parasitized bollworm eggs at significantly higher rates on tomato than on corn (Nordlund et al., 1984). Tomato contains a synomone(s) [a substance produced or acquired by an organism that when it contacts an individual of another species in the natural context, evokes in the receiver a behavioral or physiological reaction that is adaptively favorable to both emitter and receiver (Nordlund and Lewis, 1976)] that stimulates host habitat location behavior in *Trichogramma pretiosum* (Nordlund et al., 1985a, b). Compounds in the sex pheromone used by bollworm females also stimulate host selection behavior by *Trichogramma pretiosum* (Lews et al., 1982). Once a host egg is located, chemicals in the accessory gland secretaion, used by the female moths to attach eggs to the substrate, are important in host recognition (Nordlund et al., 1987).

Host plant resistance characters influence *Trichogramma pretiosum* parasitism of bollworm eggs on cotton (Treacy et al., 1985, 1987 a, b). Fewer eggs were parasitized on pilose cotton phenotypes compared to smoothleaf and hirsute cottons due to inhibition of movement of *Trichogramma pretiosum* females over leaf surfaces by the higher density of cotton leaf trichomes (hairs). The nectariless character reduces parasitism of bollworm/tobacco budworm eggs when compared to nectaried cotton by both *Trichogramma pretiosum* and naturally occurring *Trichogramma* spp.

Adult *Trichogramma* are generally highly susceptible to broad-spectrum insecticides (Jacobs et al., 1984; Bull and Coleman, 1985). Thus, their use in integrated pest management and periodic release programs will likely be limited to systems where insecticides are not used or are used only sparingly.

There has been considerable research effort expended to bring about practical use of *Trichogramma* in periodic release programs. To date the results have been mixed (Ridgway and Morrison, 1985). In the United States, emphasis has been directed toward use of *Trichogramma pretiosum* to control bollworm/tobacco budworm on cotton, a very complicated system. Ridgway and Morrison (1985) identified several research areas that, if addressed, could likely remove technical barriers to the practical use of *Trichogramma:*

- Selection of the most effective species or strain;
- Reduction of loss of efficiency resulting from dispersal;
- Improvement of production and release efficiency;
- Increased knowledge of the relationships between the numbers of *Trichogramma* and pests and changes in yield;
- Improved prediction and survey method for pests and naturally occurring predators and parasites; and,
- Design and implementation of insect management systems that will eliminate or substantially reduce insecticide interference.

FLIES

Archytas marmoratus—*Archytas marmoratus* is a large [about 1/2 inch long (12 to 13 milimeters)] tachinid parasite which is found throughout the southern United States to Peru and in the West Indies (Sabrosky, 1955; Sabrosky and Arnaud, 1965; Ashley, 1979) (Plates 3-21 and 3-22). It is a larviparous (deposits live maggots rather than eggs) larval-pupal parasite can attack a number of lepidopterous hosts (Table 10). This species is generally more abundant late in the season, though it was collected every month of the year, except February, near Brownsville, Texas (Vickery, 1929). Archytas marmoratus is a major parasite of bollworm/tobacco budworm and has been reared

Table 10. Hosts of the parasite, *Archytas marmoratus*.

Host	Source/reference
Black cutworm	Thompson (1951)
Hyblaea puera Cramer	Thompson (1951)
Mocis repanda F.	Thompson (1951)
Mocis latipes	Scaramuzza (1946)
Leucania latuiscula	Vickery (1926)
Fall armyworm	Vickery (1926)
Spodoptera latifascia	Patton (1958)
Armyworm	Vickery (1926)
Bollworm	Hughes (1975)
Tobacco budworm	Hughes (1975)
Heliophila spp.	Vickery (1915)
Laphygma spp.	James (1953)

from bollworm/tobacco budworm larvae collected from alfalfa, corn, cotton, sugarcane and tobacco (Quaintance and Brues, 1905; Vickery, 1926; Bibby, 1942; Bottrell and Arnold, 1968; Bottrell et al., 1968; Neunzig, 1969; Miller, 1971; Shepard and Sterling, 1972a). Shepard and Sterling (1972a) found that 43 percent of the parasites recovered from bollworm/tobacco budworm spp. larvae collected from cotton growing near Angleton, Texas were *Archytas marmoratus.* It was the only parasite found attacking bollworm larvae in whorl and early tassel-stage corn growing near Tifton, Georgia (Gross et al., 1976).

Archytas marmoratus females larviposit their bluish green maggots on foliage rather than directly on the host larvae (Hughes, 1975). Larviposition is stimulated by a kairomone from the host. Nettles and Burks (1975) found that a protein, with a molecular weight of 30,000 ± 5,000, present in tobacco budworm larval frass, hemolymph and whole body extract, stimulates larviposition. The maggots then attach themselves to hosts that crawl by and enter the host integument; they kill the host after it pupates (Hughes, 1975).

During larviposition, the free-living first instar maggots are anchored individually to the substrate by the chorion, which is compressed and cup-like, enveloping the caudal (rear) end of the maggot. The maggots lay horizontally on the substrate until they are disturbed and then assume a vertical position, and wave about in a circular motion. Hughes (1975) found that maggots, larviposited on young corn plants in rearing rooms (16 hours photophase, 55 percent relative humiidity) lived for 5 to 6 days at 80.6F (27C) and 13 to 14 days at 69.8F (21C). The maggots attach to host larvae and normally penetrate the host's integument within 12 hours. While the host's integument is being cast off during molts, the maggots leave the old integument, move to the new integument, and penetrate. This press continues until pupation, which occurs in an underground tunnel excavatged by the host larva. During pupation the maggots move from the old integument over the surface of the pupae and enter under the posterior wing pad margins. After penetration, the parasite begins development, goes through three larval instars and then pupates within the host's remains. Generally, only one puparium is formed per host. Developmental times at 80.6F, are 22 to 46 hours for first instar, 2 to 4 days for second instar and third instar lasts for 3 to 4 days. At 69.8F, the time between host pupation and parasite pupation is 8 to 10 days (Hughes 1975). Because the pest is killed in the pupal stage, parasitized larvae cause as much damage on cotton as unparasitized larvae. Thus, this parasite might be useful in a long-term population reduction program, but not for direct therapeutic control.

Hughes (1975) reared *Archytas marmoratus* from fourth to sixth instar bollworm and third to sixth instar tobacco budworm larvae collected from tobacco near Clayton, North Carolina. He found that maggots would readily attach to second to fifth instar hosts.

Archytas marmoratus are relatively long-lived insects with females living longer than males. Hughes (1975) reports that at 69.8F, females lived an average of 72.8 days while at 80.6F, they lived an average of 51.2 days; males lived 19.0 and 9.8 days at these respective temperatures. Adults emerge during warm periods in the winter and it appears that these adults are able to survive the winter (López, unpublished data). No diapause apparently is involved in the overwintering of this parasite at least when parasitizing bollworm/tobacco budworm in the fall for overwintering. The females exhibited a prelarvipositional period of 14.6 and 10.9 days and a larviposition period of 36.7 and 38.0 days at 69.8F and 80.6F, respectively. Fecundity was also influenced by temperature, with a mean of 1845 and 2828 maggots produced per female at 69.8F and 80.6F, respectively. Gross and Johnson (1985) report on procedures for large scale rearing of *Archytas marmoratus.*

Eucelatoria bryani—One of the most common tachinid parasites of bollworm/tobacco budworm larvae is *Eucelatoria bryani,* (Jackson *et al.*, 1969; Bryan *et al.*, 1970; Werner and Butler, 1979). It ranges from Mississippi, north to Missouri, west through Kansas to Arizona and south through Mexico to Nicaragua and El Salvador (Sabrosky, 1981). It also has been introduced into India and Trinidad for control of *Helicoverpa/Heliothis* (Sabrosky, 1981). This tachinid is a small [5/32nds to 5/16ths inch long (4 to 8 millimeters)], active, grayish-black fly with a reddish tinge at the tip of its abdomen (Plate 3-23). This parasite also can attack cabbage looper larvae; however, for all practical purposes it is limited to bollworm/tobacco budworm larvae. It has a much more narrow host range than does the closely related species, *Eucelatoria armigera* (Coquillett), found in California (Bryan *et al.*, 1970). *Eucelatoria* sp. (probably Eucelatoria bryani) was the most common tachinid parasite of bollworm/tobacco budworm trapped by Werner and Butler (1979) in cotton near Phoenix, Arizona. It was most common in late June and early July.

Most published studies on the biology of *Eucelatoria bryani* have used fourth and fifth instar bollworm/tobacco budworm larvae. However, *Eucelatoria bryani* can successfully parasitize second through fifth instar and prepupal bollworm larvae in the laboratory (Martin et al., 1989). These findings mean that this parasite may be a more prising biological control agent than was previously though because it can attack a broader range of larval stages.

Eucelatoria bryani has three larval instars: the first instar stage lasts for about 28 hours; the second for about 32 hours; and the thrid for about 36 hours at 84.2F (29C) (Ziser and Nettles, 1978). The larvae then emerge from the host, form puparia (hardened cases in which the pupa is formed) and pupate. Emergence from the host in the field occurs from the fully developed host larva that has dropped from the plant and excavated a tunnel underground in preparation for pupation. Emergence from the host and formation of a puparium occurs: (a) when all available food is consumed, (b) when the maggot has reached maximum size; or (c) if the humidity of the maggot's environment decreases (Ziser and Nettles, 1978). As with insects in general, temperature has a major influence on the time required for development and on the longevity of this parasite (Tables 11 and 12). *Eucelatoria bryani* is similar to Archytas marmoratus in that the adults emerge during warm periods in the winter and the adults are apparently able to survive the winter (López, unpublished data).

Table 11. Average length of developmental stages in days of the parasite, *Eucelatoria bryani*[1], in tobacco budworm at different temperatures[2].

Rearing Temperature	Average number of days		Average total number of days to complete development
F (C)	Larval	Pupal	
59 (15)	14.2	32.4	46.6
68 (20)	6.7	14.9	21.6
77 (25)	4.7	8.9	13.6
86 (30)	3.8	7.3	11.1

[1] *Eucelatoria* sp. from Bryan et al. (1970) was later identified as *Eucelatoria bryani* by Sabrosky (1981).

[2] Data from Bryan et al. (1970).

Table 12. Average longevity in days of males and females of the parasite, *Eucelatoria bryani,* under different constant temperature regimes.[1]

Temperature F (C)	Average longevity in days	
	Male	Female
68 (20.0)	52.5	61.8
77 (25.0)	34.1	44.1
86 (30.0)	21.1	31.0
90 (32.2)	14.8	22.9
95 (35.0)	11.1	17.9

[1] Data from Bryan *et al.* (1972).

The prelarviposition period of *Eucelatoria bryani* females ranges from five to nine days and the larviposition period ranges from one to 29 days, depending on temperature. Larviposition by *Eucelatoria bryani* peaks during the first 10 days of the female's larviposition period, when the insects were held at 86F (30C). *Eucelatoria bryani* parasitized more larvae, in the laboratory at 77 to 86F (25 to 30C) than at lower (68F) or higher (90F) temperatures (Bryan et al., 1972).

The host selection behavior of *Eucelatoria bryani* females involves responses to a number of semiochemicals. They are attractedto a variety of plants by volatile semiochemicals. Nettles (1980) found okra leaves to be more attractive than cotton leaves. Martin et al. (1990) found that several other plants/plant parts, including corn silks, pigeon pea flowers, tobacco flowers, tomato leaves and sorghum panicles are attractive to females, while devil's claw (unicorn plant) leaves and cotton leaves are not. A kairomone from the cuticles of tobacco budworm larvae, which is extractable in chloroform: methanol (1:1), induces larviposition behavior in *Eucelatoria bryani* females (Burks and Nettles, 1978). The hosts's diet affects the attractiveness of the host in an olfactometer (Nettles, 1980). The flies do not respond to either southern armyworm, *Spodoptera eridania* (Cramer), or saltmarsh caterpillar, *Estigmene acrea* (Drury).

Nettles (1982) reported that flies aggregated on filterpaper that had been treated with various materials from tobacco budworms, including fresh frass, hemolymph, vomit, and a hexane extract of frass.

Eucelatoria bryani females stand on the host larva to larviposit, and in a single very rapid motion, use an abdominal barb to rip the host's integument and the oviscapt to inject maggots into the host. Jackson *et al.* (1969) reported finding as many as 20 maggots in a single host immediately after parasitization.

SUMMARY

By improving our understanding of the biology, ecology, and impact of predators and parasites, it has been possible to develop models capable of forecasting the economic impact of pests and their natural enemies. Though there has been considerable progress, there is a great need for expanding and validating models under practical field conditions. This should lead to systems in which it is possible to accurately estimate the true costs and benefits of all pest management actions.

Claims of the importance of various groups or species of natural enemies in checking the abundance of plant-eating arthropods of cotton are generally lacking conclusive evidence. For example, there is a shortage of life table information that identifies all mortality throughout the total generation of the host and which identifies the precise cause of mortality of each individual. Thus, it is virtually impossible to make claims of importance based on evidence of irreplaceable mortality. Until life tables are completed for each key arthropod pest of cotton, we will continue to be forced to make assumptions based on fragmented studies in the literature. Complete life tables, similar to those of Sturm *et al.* (1989) for boll weevils, are needed from untreated cotton fields in several locations in the Cotton Belt over several years. Without this information, it will be impossible to develop highly accurate models using the total complex of predators, parasites and pathogens designed to forecast insect/mite pest economics and to understand the complex linkages between the plant, insect/mite pests, and their natural enemies. In this chapter, we present evidence and summarize the importance of the species of those natural enemies which presently are considered to be significant; however, future studies as well as changes in the agroecosystem brought about by man, by selection or that result from changes in the law will undoubtedly modify our choices.

This review of how different factors influence the biology, ecology and efficacy of selected natural enemies of arthropod pests of cotton identifies factors that may be manipulated to maintain or increase the densities of the natural enemy complex or their suppressive effects on pest populations in cotton fields. These manipulations involve the prision of environmental requisites, use of semiochemicals and modification of production or cropping practices. In the short term, the most immediate opportunities for maximum utilization of the natural enemy complex are probably in the modification of production or cropping practices. In the longer term, we must continue to explore the potential of manipulations which require the provision of environmental requisites and the use of semiochemicals. Pressure from society will continue to increase for a more biorational approach to pest management in cotton. A major basis for the approach will likely be the cultural and biological control of cotton pests. Maximum utilization of natural enemies will play a major role in cotton pest management programs that are compatible with sustainable agriculture ideals.

Chapter 3

APPENDIX

The color plates that follow in this appendix are photographs of some of the predators and parasites that are discussed in this chapter. Some of these photographs depict a predator feeding on a cotton insect or mite pest; other photographs depict a parasite in the act of parasitizing a cotton insect pest.

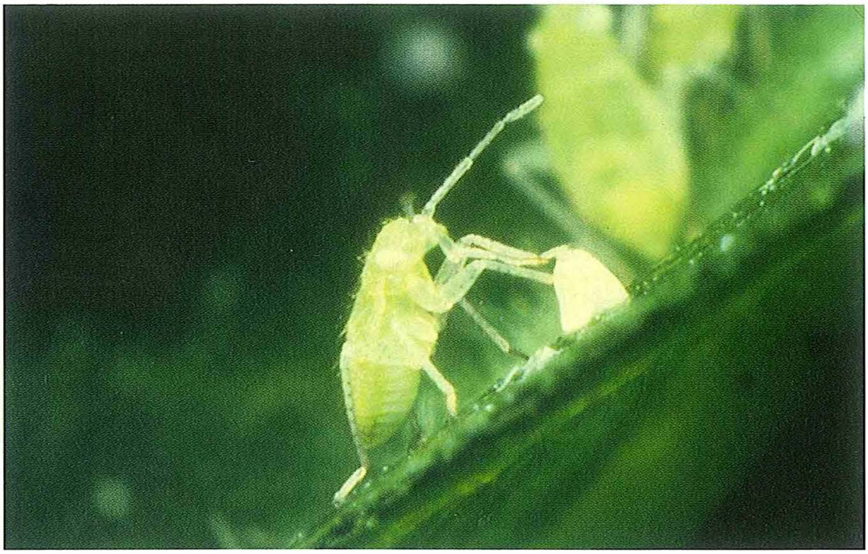


Plate 3-1. Cotton fleahopper, *Pseudatomoscelis seriatus,* nymph feeding on an egg of the bollworm, *Helicoverpa zea.*

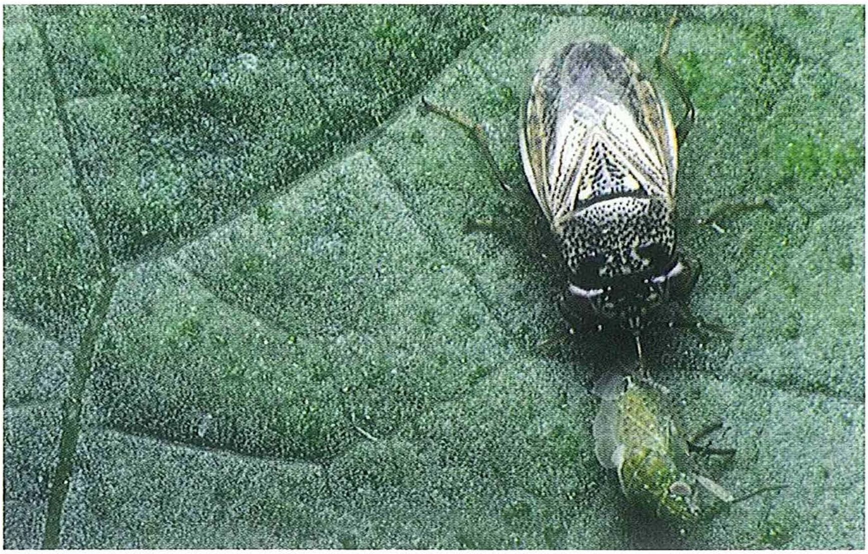


Plate 3-2. Adult *Geocoris* (bigeyed bug) feeding on an adult of the cotton fleahopper.

Plate 3-3. Nymph of *Geocoris punctipes* feeding on eggs of the bollworm.

Plate 3-4. Adult of *Chrysoperla rufilabris.*

Plate 3-5. Narrow black or dark-red band from eye to mouth over the genae (lateral part of the head) on the adult of *Chrysoperla carnea,* common green lacewing.

Plate 3-6. Larva of common green lacewing, *Chrysoperla carnea,* feeding on a bollworm egg.

Plate 3-7. Larva of *Chrysoperla rufilabris* feeding on a bollworm larva.

Plate 3-8. Eggs of *Chrysoperla* on a cotton leaf. Eggs of common green lacewing, *Chrysoperla carnea* and *Chrysoperla rufilabris* (no common name) are oviposited singly and not in groups as shown.

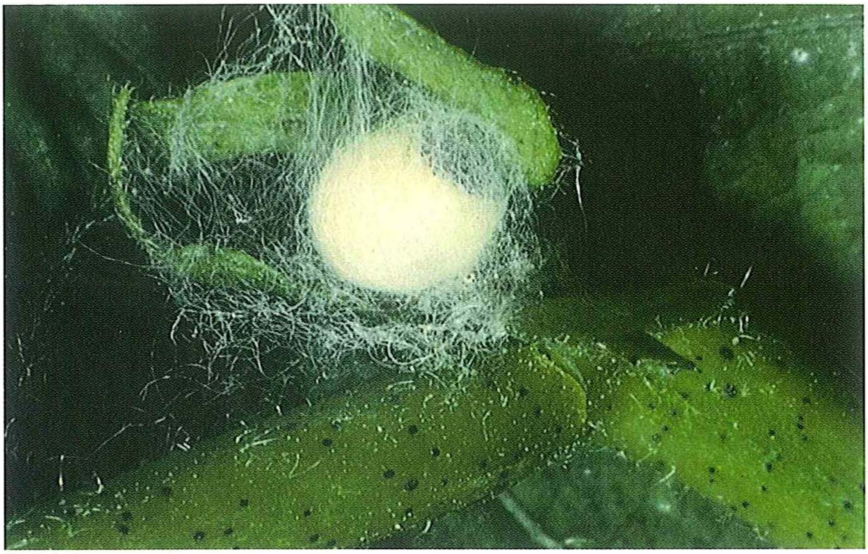


Plate 3-9. Cocoon of common green lacewing, *Chrysoperla carnea* on a cotton leaf.

Plate 3-10. Adult of minute pirate bug, *Orius tristicolor,* feeding on a bollworm larva.

Plate 3-11. Nymph of insidious flower bug, *Orius insidiosus.*

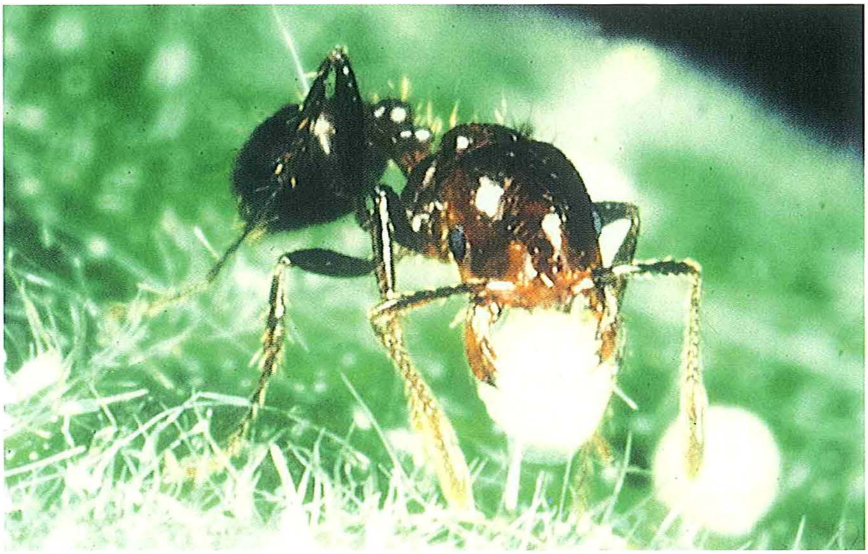


Plate 3-12. Red imported fire ant, *Solenopsis invicta,* feeding on a bollworm egg.

Plate 3-13. Striped lynx spider, *Oxyopes salticus,* feeding on a cotton fleahopper.

Plate 3-14. Winter spider, *Cheiracanthium inclusum,* feeding on a bollworm larva.

Plate 3-15. Ridge-faced crab spider, *Misumenoides formosipes* (Walckenaer), feeding on a cotton fleahopper.

Plate 3-16. Celer crab spider, *Misumenops celer,* feeding on a cotton fleahopper.

Plate 3-17. Black and white jumping spider, *Phidippus audax,* feeding on an adult boll weevil.

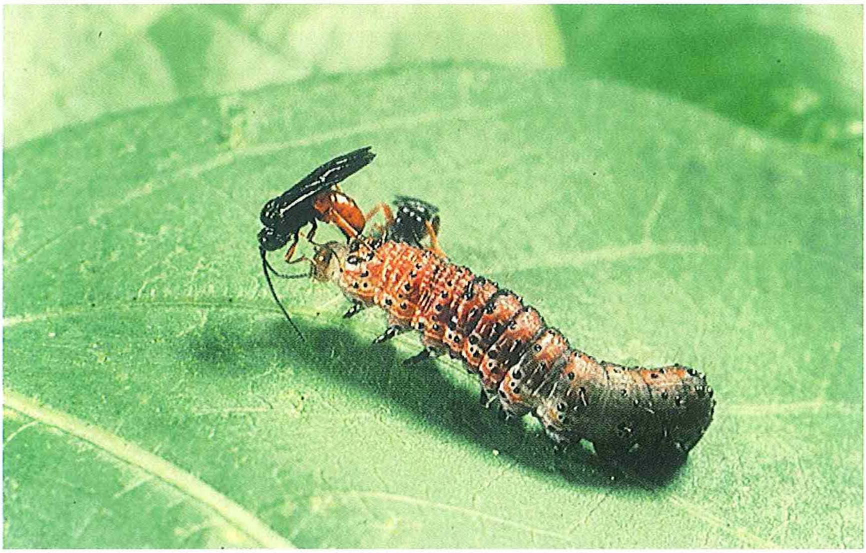
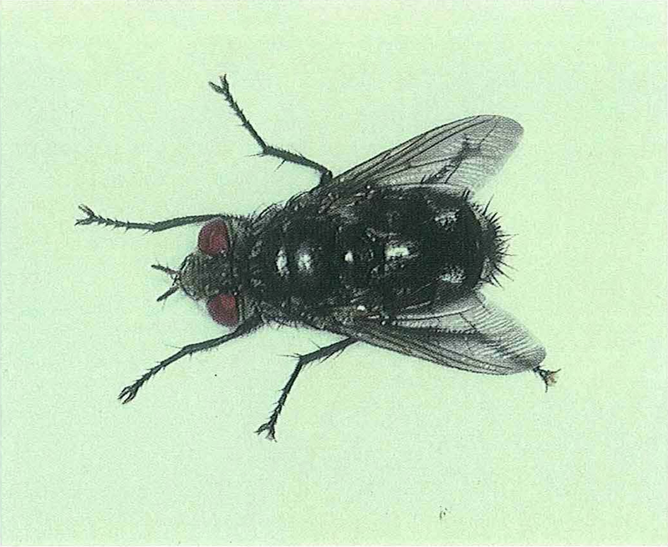


Plate 3-18. *Microplitis croceipes* parasitizing a bollworm larva. (Photo courtesy of the USDA, ARS Information Office, Beltsville, MD.)

Plate 3-19. *Cardiochiles nigriceps* feeding at a nectary on a cotton leaf. (Photo courtesy of S. B. Vinson, Department of Entomology, Texas A&M University, College Station, TX.)

Plate 3-20. *Trichogramma pretiosum* parasitizing a bollworm egg. (Photo by Jack Kelly Clark, courtesy of the University of California Statewide IPM Project, Davis, CA.)



Plates 3-21 and 3-22. Adult of the parasite *Archytas marmoratus.* (Photos courtesy of Harry R. Gross and James E. Carpenter, USDA, ARS, Insect Biology and Population Management Laboratory, Tifton, GA.)

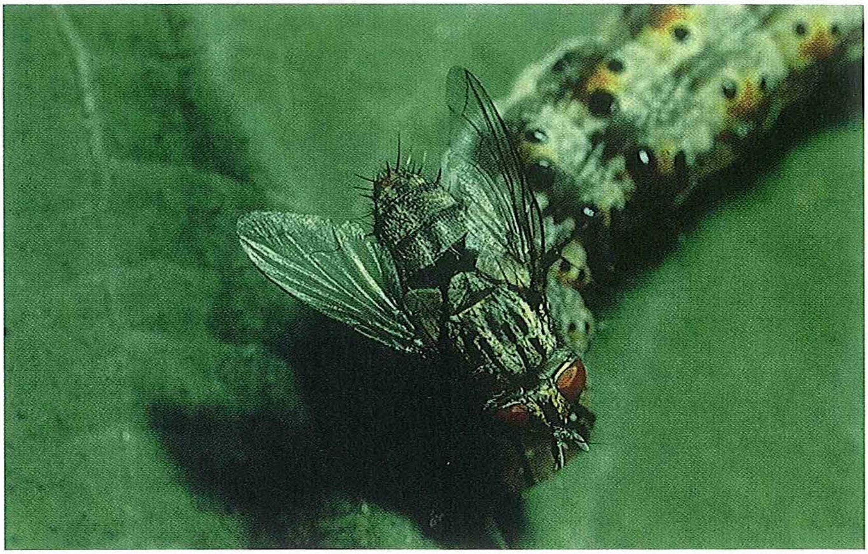


Plate 3-23. *Eucelatoria bryani* parasitizing a bollworm larva. (Photo courtesy of William C. Nettles, Jr., USDA, ARS, Subtropical Agricultural Research Laboratory, Weslaco, TX.)