Chapter 4

SHORT- AND LONG-RANGE MOVEMENT OF INSECTS AND MITES

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INTRODUCTION

Agroecosystems of annual crops such as cotton provide a transient reproductive habitat for many economically damaging insects and other pests. The cotton field is a dynamic habitat (Cross, 1983) and derives most of its arthropod populations from surrounding natural or cultivated plants. The role of both managed and unmanaged hosts in producing pest and beneficial species of arthropods invading cotton fields has long been acknowledged and will be addressed in discussions of specific insects in this

chapter. Mobility is a major factor in the population dynamics of organisms using cotton as a temporary reproductive habitat. Although the role of long distance movement on population dynamics in agricultural systems is not as clearly defined, or as well understood as the localized movement between and within fields, increasing circumstantial evidence indicates that many cotton pests, especially Lepidoptera, are capable of long distance movement.

Ridgway (1986) suggested that the choice of control strategies for insects should be based on specific criteria, including the target insect's dispersal characteristics. Ridgway further stated that understanding the quantitative population ecology of the bollworm, *Helicoverpa zea* (Boddie) and the tobacco budworm, *Heliothis virescens* (F.) (appropriate for some other insects as well) is critical for guiding future research in control tactics. Understanding migratory and dispersal capabilities of highly mobile insects is pivotal in determining the possible success or failure of many control strategies.

BOLLWORM/TOBACCO BUDWORM

The *Helicoverpa/Heliothis* genera have a worldwide distribution and their pest status is attributed, in part, to their mobility (Farrow and Daly, 1987). Due to this mobility as well as a highly polyphagous (ability to feed on many kinds of food [plants]) behavior, *Helicoverpa/Heliothis* are well adapted to exploitation of unstable habitats such as annual crops. These behavioral traits facilitate the rapid deployment of populations between fields as well as between crops and naturally occurring host plants.

The classification of movements observed in *Helicoverpa/Heliothis* adult populations has been difficult (Fitt, 1989), and various terminologies to describe their mobility abound. Farrow and Daly (1987) defined *Helicoverpa/Heliothis* movement as short-range <.6 mile (<1 kilometer), long-range 0.6 to 6 miles (1 to 10 kilometers) and migratory 6 to 300 miles (10 to 500 kilometers). However, they recognized that distinctions between these categories were rather ill-defined, and that the scale of movement depended on atmospheric conditions, distribution of suitable habitats and moth behavior.

SHORT-RANGE MOVEMENT

Short-range movement of *Helicoverpa/Heliothis* as defined by Farrow and Daly (1987) includes much of the movement involved in individual survival (feeding and seeking daytime refuge), and attraction to host plant concentrations for oviposition and mate-seeking. Within a localized adult population where suitable host plants abound, this type of movement begins near sundown and may continue at various levels of intensity throughout the night. Short-range movement usually occurs within or immediately above the crop canopy with the insects oriented up- or cross-wind. Orientation during short-range movement is probably due to responses to chemical stimuli (Lingren and Wolf, 1982) produced by the plant or by sexually receptive females (pheromonal stimuli). Various behaviors associated with this type of movement were described by Raulston *et al.* (1975); Raulston *et al.* (1976); Lingren *et al.* (1977); Lingren *et al.* (1979); and Lingren and Wolf (1982).

Agriculturally important hosts such as cotton may provide an ideal (although temporary) habitat for colonizing adults by providing them both shelter, food and attractive reproductive sites (for mating and oviposition). However, movement between fields and crops occurs resulting in a constant redistribution of the adults (Haggis, 1982; Joyce, 1982; Stinner *et al.*, 1982).

LONG-RANGE MOVEMENT

Long-range movement by *Helicoverpa/Heliothis* as defined by Farrow and Daly (1987) resulting in a displacement of a few kilometers, in many instances can still be considered appetitive or trivial since it may involve the seeking of mates, feeding sources and refuge. However, long-range movement which can occur within a few minutes may also involve the searching for more attractive host sites. Orientation and displacement associated with this movement is usually downwind and occurs within the first few tens of meters above the crop canopy. Observations using high intensity light beams and night vision goggles indicate that such movement begins at dusk and that the adults ascend to at least a height of about 100 yards (92 meters), which was the range limit of equipment used.

Long-range movement of corn earworm (same as bollworm) may also result in the redistribution of adults between habitats within an area. As the more attractive hosts (such as corn) mature, adults begin to colonize crops such as tomatoes, cotton and soybean which are considered to be less attractive hosts (Quaintance and Brues, 1905; Garman and Jewett, 1914; Pepper, 1943; Stinner *et al.*, 1982; Raulston *et al.*, 1986a; Raulston *et al.*, 1986b). Snow *et al.* (1969) reported that radiolabled bollworms, which developed in a centrally located corn field on the island of St. Croix, dispersed and concentrated around areas with attractive host plants.

Haggis (1982) analyzed the distribution of *Helicoverpa armigera* (Hübner) eggs over a 3200 square mile (8300 square kilometers) area of the Sudan Gezira and found that within each two to three day observation period, two or more significantly different levels of infestation occurred, each covering areas up to several thousand square miles with continuously changing boundaries. Haggis suggested that the major cause for the fluctuating population boundaries was a constant redistribution of adults with changing synoptic (over a broad area) and mesoscale (localized) weather patterns.

MIGRATORY MOVEMENT

Migratory movement exceeding 60 miles (100 kilometers), provides another mechanism for *Helicoverpa/Heliothis* to exploit ephemeral (temporary or short- term) habitats. This type of movement, in many instances, appears to be facultative in nature (Hackett and Gatehouse, 1982) and may occur in response to a decaying habitat. Migratory movement typically begins at dusk (Lingren and Wolf, 1982; Drake, 1984, 1985; Wolf *et al.*, 1986) with the adults rapidly ascending to an altitude of up to 1000 yards (914 meters). Radar observations (Drake, 1985; Wolf, 1986) indicate that migrants frequently form layers near or just above the maximum wind velocity associated with nocturnal low-level jets (airstreams). Wind velocity in these airstreams fre-

quently exceed 30-36 miles per hour (50-60 kilometers per hour) and can transport migrating moths over 180 miles (300 kilometers) during a five-hour flight. Drake and Farrow (1988) presented an excellent review on the atmospheric structures that provide transport mechanisms facilitating migratory movement.

Evidence that *Helicoverpa/Heliothis* undergo migratory movement includes the fact that they annually invade areas beyond their overwintering range. Also, they have been detected in areas where they do not breed and marked individuals have been captured many miles (kilometers) from their release sites. The overwintering range of the bollworm has been reported to extend northward to about 40 degrees north latitude (Snow and Copeland, 1971). However, Hardwick (1965) reported that in some years the bollworm is found up to 50 degrees north latitude. Hardwick (1965) also indicated that the overwintering range of *Helicoverpa armigera* is roughly bordered by 40 degrees north and south latitudes; however, this species has been reported as far north as Narva, Estonia, at about 59 degrees north. French and Hurst (1969) documented the arrival of *Helicoverpa armigera* in the British Isles at about 51 degrees north latitude in July 1968. Through correlation with meteorological events, they were able to backtrack the insects to their probable origin in northwestern Spain or north Africa, a distance of 480 to 960 miles (800 to 1600 kilometers). Callahan *et al.* (1972) captured bollworm moths in light traps mounted on top of a 318 yard (290 meter) television tower located near Pelham, Georgia. They concluded that these moths were in migratory flight. Sparks *et al.* (1975) captured bollworm moths in light traps located on unmanned oil rigs in the Gulf of Mexico 96 miles (160 kilometers) south of Jeanerette, Louisiana and determined that these insects were transported to sea by frontal movements. Haile *et al.* (1975) reported movement of released tobacco budworm and bollworm moths from St. Croix to the islands of St. Thomas and Veiques, a distance of 36.6 and 43.2 miles (61 and 67 kilometers) respectively. Released laboratory reared bollworm moths near Tifton, Georgia dispersed up to 15 miles (25 kilometers) in one night and up to 43.2 miles (72 kilometers) in one to four nights (Sparks, 1972). In a similar study near Brownsville, Texas, Hendricks *et al.* (1973) recaptured tobacco budworm moths up to 67.2 miles (112 kilometers) downwind from the site of their release. Raulston *et al.* (1982) captured feral (wild) tobacco budworm moths in the Lower Rio Grande Valley and released them near San Fernando Tamaulipas, Mexico. Subsequently, some of these moths were recaptured in the Lower Rio Grande Valley, after they had flown a distance of 96 miles (160 kilometers) from San Fernando.

Asynchrony (lack of synchrony) between emergence of moths from local populations and the occurrence of initial trap captures also has provided evidence of migratory movement (Stadlebacher and Pfrimmer, 1972; Raulston, 1979; Hartstack *et al.*, 1982). Furthermore Hendrix *et al.* (1987) collected bollworm moths in Arkansas with pollens that the moths carried at least 450 miles (750 kilometers).

IMPLICATIONS OF *HELICOVERPA/HELIOTHIS* MOBILITY

Since the advent of efficient pesticides, control strategies for *Helicoverpa/ Heliothis* have relied on field-by-field defensive measures to suppress larval populations. However, the indiscriminate use of pesticides, which were often applied on an empir-

ically scheduled basis, is no longer an environmentally or economically viable pest management option. The constant redistribution of adult populations through short- and long-range nocturnal movements requires that susceptible crops such as cotton be constantly monitored for the presence of egg/larval populations to properly time control measures, if needed. Furthermore, the influence of movement in developing *Helicoverpa/Heliothis* control strategies that do not rely completely upon pesticides, must be addressed (Fitt, 1989). The high mobility characteristics of *Helicoverpa/Heliothis* may often negate the possibility of adequately predicting egg and larval populations based on the immediate past history of individual fields since adults may be derived from adjacent crops and wild host plants as well as from other regions. The problems that arise as a result of adult movement is compounded in areas with diverse cropping systems where a succession of cropped host plants are available to the insect.

The mobility of *Helicoverpa/Heliothis* adults provides both opportunities and constraints for developing population suppression technology. Moth mobility allows the female to disperse her eggs over relatively large areas on a variety of hosts. This requires the use of large volumes of pesticides (with an array of negative side effects) over large areas to facilitate larval control in susceptible crops. Moth mobility also is a major constraint for developing, or even adequately researching suppression technology using pheromones as mating suppressants. Movement of previously mated females into pheromone-treated areas can effectively mask any treatment effects unless plots are large enough to reduce the possibility of immigration. The ability of *Helicoverpa/Heliothis* moths to rapidly disperse (Haggis, 1982) may also reduce the effects of natural enemies in controlling *Helicoverpa/Heliothis* populations. If inadequate populations of natural enemies are present or if their dispersal is not at the same rate as the pest into colonization areas, control will be inadequate. For example movement of beneficial insects can be affected by the occurrence of alternate food sources within a field or area. Thus, if a large biomass of relatively sessile (immobile) prey, such as aphids, were available within a field from which moths were dispersing, a concurrent dispersal of beneficial insects may not occur.

Techniques for suppressing moth populations that reduce the impact or take advantage of their mobility have been deployed or suggested. In Arkansas, the establishment of management communities resulted in a reduced number of pesticide applications being applied for control of the bollworm (Phillips, 1978). The use of management communities enables synchronous pesticide applications over a large enough area 30+ square miles (80+ square kilometers) to negate the effects of short-distance movement by moths. Another technique that may take advantage of moth mobility is the manipulation of the adult population through the use of trap crops (see Fitt 1989, for review) that provide attractive feeding or reproductive sites. Lingren *et al.* (1982), Lingren and Wolf (1982) and Lingren *et al.* (1988), suggested that a thorough understanding of the nocturnal (nighttime) behavior of moths will facilitate the development of efficient adult control technology.

The agricultural community must address the entire ecosystem within any given region to adequately determine the how, when, and where of pest population deriva-

tion. Then based on this knowledge, areawide suppression technologies as proposed by Knipling (1979) and Johnson *et al.*(1986) may be applied with success.

PINK BOLLWORM

The pink bollworm, *Pectinophora gossypiella* (Saunders) is recognized as one of the most important economic pests of cotton throughout the world. It was described in 1843 from specimens damaging cotton in India (Noble, 1969). From India the pink bollworm apparently reached Egypt in infested cottonseed shipped in 1906 or 1907, and subsequently reached the western hemisphere in infested cottonseed shipped from Egypt to Mexico between 1911 and 1913 (White, 1960). The insect was first detected in the United States in cottonseed shipped in 1916 from Mexico to Texas oil mills. Initial United States infestation was apparently eradicated in Texas using cotton-free zones and extensive cultural measures. Subsequent infestations in Louisiana, Arizona, Georgia and Florida were also eliminated (infestation still exists in wild cotton in Southern Florida) (Anonymous, 1977).

Reinfestation of the Lower Rio Grande Valley of Texas by the pink bollworm in 1936 was suspected to have occurred from moth migration from Mexico. By the mid-1950s, all the cotton growing areas in Texas, New Mexico and Oklahoma, as well as large areas of Arizona, Arkansas, and Louisana were infested. By 1965, the pink bollworm had infested all of the cotton-growing areas in Arizona and for the first time had been reported in southern California. Thus, by 1967, most cotton west of Louisiana and Arkansas except in California's San Joaquin Valley was infested (Spears, 1968).

The role of moth flight in the spread and establishment of pink bollworm infestations became of interest after unexplained reinfestations occurred in cotton in the Big Bend area of Texas. These reinfestations followed two years of cotton-free zone restrictions as well as other eradication measures that had been successful in other areas (Coad, 1929; McDonald and Loftin, 1935). Infestations also were detected in other valleys along the Rio Grande and Pecos Rivers in Texas and New Mexico, and in small isolated cotton fields located 24 to 48 miles (40 to 80 kilometers) from known infestations. Ohlendorf (1926) demonstrated that cotton fields isolated from infested cotton by 1 to 39 miles (1.6 to 65 kilometers) became heavily infested with pink bollworm by late-July to mid-October in Mexico, suggesting late-season moth flight from infested to uninfested cotton. Similarly, Fenton (1929), McDonald and Loftin (1935), and Fenton and Owen (1953) reported that cotton plots isolated by 3.6 to 72 miles (6 to 120 kilometers) from infested cotton in Texas unexpectedly became infested. Of the 90 plots investigated over a six-year study period, 18 became infested from late-September to November. Generally, rapid increases in field infestations occurred shortly after the number of pink bollworm moths captured in sticky traps increased. These authors observed that the spread and intensity of pink bollworm infestations in the southwestern part of the United States were highly correlated with southerly winds from the heavily infested Laguna district of Mexico, 192 miles (320 kilometers) away.

Using an airplane equipped with sampling nets, a number of studies of pink boll-

worm moth dispersal were made in Mexico in 1928. Pink bollworm moths were collected at altitudes of up to 984 yards (900 meters) (Glick, 1939). Similar flights over the Rio Grande Valley resulted in the collection of pink bollworm moths at altitudes ranging from 32 to 328 yards (30 to 300 meters) (Glick, 1957). Glick (1967) concluded that pink bollworm infestations in the United States were spread by moth migrations from Texas and Mexico.

Establishment of the pink bollworm in central Arizona after 1958, and the detection of infestations in southern California in 1965, increased concern about further spread into the San Joaquin Valley of California. Sharma *et al.* (1971) demonstrated pink bollworm moth catches in hexalure-baited traps placed in fallow and sorghum fields in the Imperial Valley at distances ranging from 10 to 164 yards (10 m to 150 meters) from cotton fields. The dispersal potential of pink bollworm under arid desert conditions was demonstrated by Bariola *et al.* (1973) who captured moths in four acres (1.6 hectares) of isolated cotton in the Mojave Desert 33 miles (55 kilometers) from the nearest infested cotton. Male moths were caught in hexalure-baited traps the last of May, and 6 days before first cotton flowers opened. The first larva was found in a flower on June 2, indicating the infestation resulted from oviposition by moths (immigrating at least 33 miles [55 kilometers]) which had overwintered as larvae. Kaae *et al.* (1977) also reported early season movement of pink bollworm in southern California. Manley (1986) identified both early- and late-season dispersal of pink bollworm males in Arizona using gossyplure-baited traps placed in desert habitats from 0.96 to 7.2 miles (1.6 to 12 kilometers) from cotton. The author suggested that crop phenology resulted in the observed dispersal patterns.

Stern (1979), reported pink bollworm male moth catches in gossyplure-baited traps in the desert between the Imperial, Coachella and Palo Verde Valleys of California from late-June through mid-November. These valleys are approximately 48 to 72 miles (80 to 120 kilometers) apart. One area with a large number of captured moths was approximately 19.2 miles (32 kilometers) from the nearest cotton. Graham (1978) reported that pink bollworm moths migrated approximately 24 miles (40 kilometers) from infested cotton in the same area. Stern (1979) also collected a high number of pink bollworm moths during mid-september in the Riverside-Mojave Desert area over 96 miles (160 kilometers) north of Palo Verde, Coachella and Imperial Valleys. The largest number of moths were caught following southwesterly wind and rain storms. Beasley *et al.* (1985) placed gossyplure-baited traps about every 3.6 miles (6 kilometers) between the Palo Verde and Imperial Valleys. Traps on each end of the trapline were about three miles (five kilometers) from cotton. Pink bollworm moth catches showed a small peak in late April and early May, declined after a small peak in June through July, and increased dramatically in late August. Moth trap catches in the desert corresponded to fluctuating population trends in commercial cotton fields. High moth catches in the desert early and late in the season suggested migrating individuals from the emerging overwintering population and a dispersal late in the season. Pink bollworm moth emergence in cages and male moth catches in gossyplure-baited traps have been shown positively related to

temperature and variability of wind direction and negatively related to wind speed (Beasley *et al.*, 1985; Adams *et al.*, 1987).

Native pink bollworm moths have been caught in pheromone-baited traps in the uninfested San Joaquin Valley of California each year since 1968 (USDA, Animal and Plant Health Inspection Service, unpublished reports). Moths that were caught in these traps were strongly suspected to be migrants from southern desert valley cotton growing areas, as much as 384 miles (640 kilometers) away. Wolf and Kauper (Unpublished data, Wayne W. Wolf, United States Department of Agriculture, Agricultural Research Service, Georgia Coastal Plains Experiment Station, Tifton, Georgia; Erwin K. Kauper, Metro Monitoring Service, Covina, California) conducted trajectory analysis from southern California from wind data to determine the occurrence of weather systems that could transport pink bollworm moths from the southern Coachella and Imperial valleys to the central California San Joaquin Valley. Their data show that favorable windflows were present when low pressure areas occurred off the southern California coast for approximately two days. Weather systems favorable for moth dispersal occurred ten times during a selected 13-month sampling period. This provided 25 days for potential migration.

An aggressive program involving cultural control and sterile moth releases appears to have been successful in preventing the establishment of the pink bollworm in the San Joaquin Valley. Noble (1936) showed that, after exposure for one to seven days to simulated conditions for El Paso, (altitude of 2952 feet [900 meters] and average temperature of 60F [15.5C]), pink bollworm moths resumed oviposition of fertile eggs. Also, studies have shown that the pink bollworm can overwinter in California's San Joaquin Valley (Personal Communication, A. C. Bartlett, Western Cotton Research Laboratory, USDA, ARS, Phoenix, Arizona; R. T. Staten, Methods Development Laboratory, USDA, APHIS, Phoenix, Arizona) and the Antelope Valley of California, where an average air temperature of 20F (-7.2C) occurred, and the ground was frequently frozen during December and January to a depth of three to four inches (7 to 10 centimters) (Stern 1979).

Although much of the evidence for migrating pink bollworm moths is indirect, and based on infestations or trap catches at distances from known sources of infestations, more definitive information to support moth dispersal as a source of spread and establishment of the insect has been documented. Flint *et al.* (1975b) released P^{32} radiolabeled pink bollworm moths in a cotton field and determined that they dispersed an average of about 65 yards (60 meters) from the release point within 11 to 12 hours. Under tethered, flightmill conditions, pink bollworm moths flew the equivalent of 13.2 miles (22 kilometers) during a 24-hour period at an average speed of about 0.36 miles per hour (0.6 kilometers per hour) (Flint *et al.*, 1975a). The majority of the live male moths that were captured in cotton, alfalfa, sugarbeet and desert habitats, and marked with fluorescent dyes, were recaptured within the habitat in which they were released (Flint and Merkle, 1981). These authors also reported that from 18 to 21 percent of the moths that were originally captured in desert, alfalfa and sugarbeet habitats were recaptured in cotton after they were marked and released; only 4.7 percent of the moths

that were released in cotton were recaptured in other habitats. These data suggest greater movement to cotton than from cotton during April and May.

The attractiveness of cotton over non-host habitats was further substantiated by Flint *et al.* (1987). They found that pink bollworm moth catches in gossyplure-baited traps were equally distributed in cotton, corn, alfalfa, wheat, pea and grape habitats until approximately one week prior to cotton flower bud formation. Following flower bud formation the number of moths caught in cotton fields increased dramatically, but not in non-host crop fields. Butler *et al.* (1983), found that both male and female pink bollworm moths moved into and out of cotton fields throughout the season. Catches of virgin and mated females suggest that both young as well as older females were dispersing. The mating status of dispersing pink bollworm populations is of critical importance in population dynamics of the species. Although Kaae and Shorey (1973) found male pink bollworm moths in field crops adjacent to cotton, no mating pairs were observed. However, indirect evidence obtained by placing mating stations in desert habitats indicate that pink bollworm moths mate as well under those conditions as in cotton habitats (Flint and Merkle, 1981).

Van Steenwyk *et al.* (1978), showed that pink bollworm moths marked with rubidium were highly mobile within a 10-acre cotton field from July to October. Rubidium-marked moths left the fields primarily in September and October and were captured as far as one mile from the field. Rubidium-marked moths from overwintering larvae departed from the cotton field from May through June. This corroborates the indirect evidence that pink bollworm migrate following emergence from the overwintering population (Bariola *et al.*, 1973; Beasley *et al.*, 1985), as well as late in the season (Ohlendorf, 1926; McDonald and Loftin, 1935; Beasley *et al.*, 1985).

Bartlett (1985) released laboratory-reared, dominant, dark body color pink bollworm moths (sooty strain) in cotton. Released male moths were recaptured within 24 hours in gossyplure-baited traps placed one mile from the release point. A small number of the moths were recovered up to 23 days after their release. In other studies (Bartlett and Lingren, 1984), most recoveries of released, sooty male moths occurred in gossyplure-baited traps placed downwind from the release point, suggesting the influence of wind on moth dispersal.

Short-range movement of pink bollworm moths within a cotton crop that is associated with mating and reproduction has not been studied extensively in spite of its importance in pink bollworm population dynamics. Lingren *et al.* (1978), using night vision goggles, observed pink bollworm males moving crosswind from 30 minutes to one hour before mating was observed. When males intercepted pheromone plumes from lures, they oriented upwind toward the source. In most cases, the pheromone plume did not extend over 16 yards (15 meters) from a lure, indicating that the crosswind flight is a searching mechanism to increase a male's probability of intercepting a pheromone emitting female moth. The authors also observed females moving from plant to plant while touching extended phermone glands to leaf surfaces. Presumably this "pheromone marking" aids the male in locating the receptive female. Lingren (1983) observed newly eclosed (emerged) pink bollworm moths taking short flights of

about one yard (one meter). During a second period of flight activity from three to six hours after eclosion (emergence), moths flew from one to two yards (one to two meters) with about 10 percent flying beyond viewing range. About 11 hours after eclosion most moths flew out of viewing range.

Short-and long-range flight activities played a major role in the spread and establishment of pink bollworm infestations in the United States and Mexico, and probably in other areas of the world as well. Short-range and interfield movements appear to occur at random except for directed orientation toward sex pheromone sources. Long-range movement appears to be primarily influenced by wind speed and direction. Most of the evidence for pink bollworm dispersal has been obtained indirectly. Some factors, such as cotton crop phenology, temperature, wind speed and direction and short-range attraction to the sex pheromone, gossyplure, appear to influence pink bollworm moth movement. However, the effect of these factors on dispersal have not been quantified. Also, estimates have not been made on what percentage of the population disperses during periods of flight activity. The importance of documenting the role of dispersal in the population dynamics of the species, and its implications for the development of new control technology justify extensive, in-depth research.

BOLL WEEVIL

ORIGIN AND DISTRIBUTION

The boll weevil, *Anthonomus grandis grandis* (Boheman), originated in Meso-America (southern Mexico and Central America) on plants of the malvaceous genus *Hampea* (Burke *et al.*, 1986). The boll weevil had probably achieved its present distribution in western Mexico and southern Arizona, as well as in northeastern Mexico, before the beginning of primitive cotton cultivation. Circumstantial evidence for migration of the boll weevil in the United States was obtained by documenting the extension of its range each year after the initial infestation in Texas in 1892. From 1894 to 1922, the boll weevil extended its range from 39 to 154 miles (65 to 258 kilometers) annually, (Hunter and Hinds, 1905; Hunter and Coad, 1923), and crossed non-cotton habitat extending for more than 39 miles (65 kilometers) to infest cotton.

FLIGHT ALTITUDE AND DISTANCE

Several techniques, including aerial netting, flight screens, pheromone traps and isolated cotton plots, have been employed to document the altitude at which and distance the boll weevil may move. An airplane equipped with an insect collection device was used by Glick (1939), Glick (1957) and Glick and Noble (1961) to collect the boll weevil at various altitudes over Texas and Louisiana. Boll weevils were collected during the day flying at altitudes from 6 to 667 yards (5.5 to 610 meters) from August to November. Only one weevil was collected flying at night.

Gaines (1959) captured boll weevils on 0.98 X 1.6 yards (0.9 X 1.5 meters) sticky coated flight screens from 0.98 to 18 yards (0.9 to 17 meters) above the ground with about one-fourth of the specimens collected from the lowest screens. There was a significant correlation between the number of weevils collected and the altitude of the

screens. Over 50 percent of weevils that were captured on flight screens while flying from hibernation sites in South Carolina during April to July were captured at altitudes of less than three yards (2.8 meters); only nine percent were caught above 13 yards (12.4 meters) (Taft and Jernigan, 1964). Weevils flying from a cotton field from August through December were caught at a greater height, with about 39 percent being caught above 13 yards (12.4 meters).

Rummel *et al.* (1977) used pheromone traps placed at heights of 0 to 9 yards (0 to 8.3 meters) and captured over 90 percent of the overwintered weevils flying below five yards (4.6 meters). However, during the late-summer and fall dispersal period, the number of boll weevils captured at the nine yards (8.3 meters) level increased from eight- to ten-fold. Rummel *et al.* (1977) also captured weevils at an altitude up to 133 yards (122 meters) with aircraft-towed nets during the fall of 1973.

The distance that the boll weevil may fly has been empirically determined by: (a) its flight to isolated plots or pheromone traps, (b) its movement from overwintering habitat to cotton, and (c) the capture of marked adults. Beckman and Morgan (1960) reported weevils moved into a cotton plot on St. Simon Island, South Carolina, that was about 24 miles (41 kilometers) from the closest cotton. Rummel and Adkisson (1970) found that most cotton fields infested by the boll weevil were adjacent to favorable overwintering habitat. This indicated that they were not moving great distances from overwintering habitats to the fields. Fye and Parencia (1972) found that infested cotton fields located more than about four miles (8 kilometers) from infested *Thurberia* plants in Arizona usually did not become reinfested in successive years. Fields adjacent to infested *Thurberia* plants were infested every year. In Mexico during October of 1968, Davich *et al.* (1970), using sticky-coated wing traps baited with males, captured weevils up to 43 miles (73 kilometers) from the nearest cotton. There was no indication that prevailing winds, topographical features or storms influenced movement and subsequent capture of boll weevils. Roach and Ray (1972) found in South Carolina that boll weevils from the F_1 and succeeding generations move more than 19 miles (32 kilometers) in numbers large enough to damage cotton. Pieteri and Urban (1977) captured numerous boll weevils in traps within 3.3 miles (5.6 kilometers) of cultivated cotton on the mainland; relatively few weevils were caught on Padre Island (Texas), about 2.88 miles (4.8 kilometers) from cultivated cotton; and no weevils were trapped on oil platforms in the Gulf of Mexico, more than seven miles (12 kilometers) from cultivated cotton. The lack of favorable transport systems toward the ocean probably limited flight in that direction.

Although Johnson *et al.* (1976) captured two marked boll weevils 43 miles (72 kilometers) from the point of release in Mississippi, 88 percent of the marked boll weevils were captured within 14 miles (24 kilometers) of the release point. The direction of dispersal was evenly distributed from the release point. Dickerson and Leggett (Unpublished data, W. A. Dickerson, North Carolina Department of Agriculture, Raleigh, North Carolina) captured a marked boll weevil in a cotton field D-vac sample in North Carolina that was 63 miles (105 kilometers) from its South Carolina release point.

SEASONAL MOVEMENT

A knowledge of the seasonal pattern of movement of boll weevils is important for timing cultural and chemical control strategies. Variability in the seasonal pattern of weevil movement in the cotton growing areas could be due to genetic differences in populations, climatic variations, cultivars of cotton, plant phenology, or cultural practices.

Early-season and Within Field — Many studies have documented the temporal pattern of boll weevil emergence from overwintering habitats (Fenton and Dunnam, 1929; Gaines, 1935; Davis *et al.*, 1967; Davis *et al.*, 1976; Ridgeway *et al.*, 1971; Roach *et al.*, 1971). Generally, overwintering emergence occurs between April and June. Boll weevil movement, as well as the stimuli which induce movement, varies with seasonal changes in the cotton plant, with the age structure of the population of boll weevils and with the populations physiological condition.

White and Rummel (1978) found that very few overwintered weevils entered presquaring cotton in Texas but immigration increased with maturity and number of squares. Pheromone traps consistently indicated peak flight activity of overwintered boll weevils occurring during May or early June. Ridgeway *et al.* (1971), using male-baited sticky wing traps, observed a cessation of movement in mid-June that is accompanied by the accumulation of boll weevils in cotton fields. They speculated that the presence of cotton or the age of cotton may not be the principal factor governing its seasonal movement. Further, Rummel and Bottrell (1976) found a similarity in weevil response to isolated plots of cotton and pheromone-baited traps away from cotton. They concluded that the presence of pheromone-producing male weevils in cotton was not a major causal factor in the decline of weevil response to traps. However, McKibben *et al.* (1977) determined that volatile compounds from the cotton plant attracted both overwintered and late-season migrating boll weevils in Mississippi. They concluded that plant attractants are not as important as the male pheromone in inducing the boll weevil to fly.

Within Field — Following their entry into attractive cotton fields, much of the movement by boll weevils is associated with mating, and finding suitable feeding and oviposition sites. Cross and Mitchell (1966) observed in the field that male boll weevils did not respond to females over a distance of greater than 1 to 2 inches (2.5 to 5 centimeters). However, females often sought males at a distance of more than 9.8 yards (9 meters) especially when the males were upwind. Hardee *et al.* (1969) found that females responded to males from a distance of 90 yards (82 meters) in a cotton field. Boll weevil oviposition occurs primarily during the day from 0900 to 1500 hours (Howe, 1916). McGovern *et al.* (1987) found that females moved more when searching for pristine squares in heavily infested fields. Females normally reject squares with an egg puncture and continue searching for uninfested ones. Other behaviors associated with in-field movement of boll weevils as effected by abiotic factors, such as temperature, rain and wind and biotic factors such as cotton cultivars were reported by Gilliland and McCoy (1969), Jones and Sterling (1978), Mitchell and Mistric (1965) and Mitchell *et al.* (1972).

Mid-to Late-Season Dispersal — Fenton and Dunnam (1928), Taft and Jernigan (1964) and Hopkins *et al.* (1971) observed a general mid-season dispersal of boll weevils, even in slightly infested fields from mid-June through August. Several factors appeared to have influenced their dispersal behavior. Fye and Bonham (1970) observed that a lack of oviposition sites triggered dispersal when populations increased to a level where there was less than one unpunctured square per pair of weevils. Guerra (1986) released marked boll weevils in Texas that had been reared from squares or bolls. He indicated that square-reared weevils were physiologically oriented toward feeding and oviposition rather than flight from cotton. In contrast, boll-reared weevils exhibited a tendency to disperse when they were released either in or out of cotton fields. Mitchell and Mistric (1965) observed that squares and bolls in newly infested fields receive an unusually large number of egg punctures, indicating an immigration of reproductive females. Cross (1976) found that the capture of dispersing weevils in traps outside of cotton began the first week of August in south Mississippi.

ENTRY INTO OVERWINTERING HABITAT

Wade and Rummel (1978) examined leaf litter in the rolling plains of Texas from August 1975 to March 1977 and found that most overwintering weevils move into hibernation sites in October and November. Apparently, only a small percentage of a diapausing population enters an overwintering habitat during late August and early September. However, Gaines (1935) found weevils in Spanish moss as early as September 1 in Mississippi. Most studies have indicated that weevils fly a relatively short distance to enter a hibernation habitat. Up to 90 percent of the hibernating weevils are located within 55 yards (50 meters) of cotton field edges (Bondy and Rainwater, 1942; Beckham, 1957; Fye *et al.*, 1959).

Diapausing boll weevils that enter leaf litter may not remain in one spot throughout the winter. Some move in response to changing stimuli such as temperature and moisture. Hopkins *et al.* (1972) observed that boll weevil movement in overwintering habitat increases as litter moisture rises. Mitchell (1971) found that diapausing boll weevils marked with P^{32} and placed in leaf litter in Mississippi did not move more than 24 inches (61 centimeters) from their original release point during January and February. In March and April, nine weevils moved more than 5.6 yards (5.2 meters) and one male moved 15 yards (14 meters). Some weevils moved quite extensively without moving very far from their release point.

WHITEFLY

Species of whiteflies infesting cotton in the United States include the iris whitefly, *Aleyrodes spiraeoides* (Quaintance); bandedwinged whitefly, *Trialeurodes abutilonea* (Halderman); greenhouse whitefly, *T. vaporariorum* (Westwood) (Byrne and von Bretzel, 1987; T. F. Leigh and J. B. Graves, Personal communication, Department of Entomology, Louisiana State University, Baton Rouge, Louisiana); and the sweetpotato whitefly, *Bemisia tabaci* (Gennadius). Whiteflies are generally characterized as

occasional or sporadic pests of cotton in the United States, but the sweetpotato whitefly has become a pest of increasing importance since 1981 (Duffus and Flock, 1982; Johnson *et al.*, 1982). Because sweetpotato whitefly damages cotton both directly and indirectly, steps now are commonly taken to reduce its populations. When dense populations occur sweetpotato whitefly may extract enough plant material to reduce yields. Also, the honeydew from large populations of this pest may interfere with photosynthesis and serve as a medium for a lint-staining sooty fungi. Finally, sweetpotato whitefly serves as a vector for cotton leaf crumple virus (Brown and Nelson, 1984).

The sweetpotato whitefly was first described in 1889 on tobacco in Greece. Outbreaks were reported on cotton in India in the 1920s (Husain and Trehan, 1933). The sweetpotato whitefly subsequently spread throughout the Near and Far East and Central and South America (Horowitz, 1986). In each country where this whitefly has appeared, its presence initially is of little consequence but, after one or two years, populations become epidemic. Although reasons for sudden outbreaks remain unclear, they probably are related to a rapid increase in pesticide resistance, the impact of pesticides on natural enemies and changes in agronomomic practices, such as the extension of cropping seasons (Gameel, 1969; Dittrich *et al.*, 1986; Von Arx *et al.*, 1983; Meyerdirk *et al.*, 1986).

Whiteflies have a unique life cycle. Despite the fact that they experience incomplete metamorphosis, the immatures are called larvae because they develop an apparant "pupal" case. Eggs, commonly laid on the underside of leaves, hatch into first instar larvae which are mobile. These "crawlers" seldom move more than a few inches and soon settle to feed, almost always on the leaf where the egg was laid. The subsequent second, third and fourth instars are sessile (immobile). Adults emerge from "pupal" cases and, after a brief teneral period (time of hardening of the exoskeleton), are capable of flight. Movement of any spatial consequence is limited to the adult stage.

Because whiteflies are tropical insects (Mound and Halsey, 1978), they obviously moved by some means to the temperate areas which they now inhabit. We have no evidence, however, that whiteflies routinely engage in the long- range migration common to other homopterous insects (Taylor, 1985).

Whiteflies may migrate shorter distances of up to 3 miles (5 kilometers) (Coudriet *et al.*, 1986; Cohen *et al.*,1986) and dense populations are routinely seen over fallow ground (Gerling and Horowitz, 1984; Byrne *et al.*, 1986). If the Southwest cotton production system serves as an example, short-range movement is apparently all that whiteflies require for survival and reproduction once they become established in an area.

In the Southwest, whiteflies overwinter in populations as actively developing individuals rather than as populations of individuals in reproductive diapause. Coudriet *et al.* (1985) found active individuals throughout the winter months in the Imperial Valley of California, and D. N. Byrne (unpublished data) made similar observations in Arizona. These insects are commonly found on *Malva parviflora* L. and annual sowthistle, *Sonchus oleraceus* L. from October until March, and on common sunflower, *Helianthus annuus* L. and field bindweed, *Convolvulus arvensis* L., in the spring. Similarly, Gameel (1969) reported that large populations of whiteflies over-

winter on weeds along river banks in Sudan. In Isreal, Gerling (1984) found sweetpotato whiteflies, using 19 plant species as winter hosts, as follows: *Abutilon grandifolium*; *Lantana camara*; *Chrysanthemum indicum*; little mallow, *Malva parviflora* L., *Gebera* spp.; *Solanum vilosum*; *Withania somnifera*; *Celtus australis*; *Loniora etrusca*; *Verbena* spp.; *Circis siliquestram*; field bindweeds; *Plumbago europaea*; *Alcea setosa*; *Tropaeolum majus*; *Calendula* spp.; and annual sowthistle. Just as in the United States, plants of some species (for example, *Lantanta camara*, *Abutilon grandifolium* and *Chrysantemum indicum*) have abundant foliage and harbor sweetpotato whitefly throughout the year; others (like annual sowthistle, *Tropaeolum majus* and *Celtus australis*) serve only as seasonal hosts.

In the Southwest, whiteflies infest a number of both crop and weedy plant species. Coudriet (1985) believes lettuce is one of the more favorable hosts since it is planted as early as August and harvested through March. Moreover, the development time for the sweetpotato whitefly on lettuce was the second shortest (19.4 days) of the 17 crop species tested. He stated that in the field, the sweetpotato whitefly completes one generation and starts another between late October and early January. Spring crops such as watermelon and cantaloupe are planted for June harvesting while alfalfa is grown year round. Cotton, the principal host for whiteflies, is planted in late March and picked at year's end. Bionomics of the sweetpotato whitefly, are similar in the Near East (Gerling, 1984) and India (Husain *et al.*, 1936), where populations overwinter on a variety of cultivated and wild plant species before moving to spring hosts such as potato and cultivated sunflower. In every situation where whiteflies are a serious problem, wild and cultivated hosts grow in close proximity and whiteflies have little difficulty finding new habitats when existing habitats become less preferred.

The sequence of events in the Southwest, which mirrors that in other parts of the world, follows a routine pattern: existence at a low level on wild or cultivated host from January through May (Coudriet, 1985); migration to early spring vegetables, such as cantaloupe, where they remain through mid-summer (Byrne, unpublished data); and movement to cotton in July and August where populations begin to build exponentially. Cotton, by far, produces the greatest number of whiteflies, considering the acres grown and the large amount of biomass it provides for oviposition and feeding sites. Furthermore, cotton is present at a time of year when environmental conditions favor population increase. In the fall, whiteflies move to newly emerged vegetables, such as lettuce where they remain until populations decline in November. Abundant suitable hosts are never lacking, but cotton contributes so prominently to the proliferation of whiteflies in the Southwest that this insect is now identified by many as a principal cotton pest.

Observations show that whiteflies accomplish their short-range aerial movements similar to aphids and other small insects (Haine, 1955). In examining the relationships among body mass, wingbeat frequency and wing loading in insects, Byrne *et al.* (1988) showed that larger, strong-flying insects seemingly use strategies, such as compensating for high wing loading with higher wingbeat frequencies similar to other flying animals. Accordingly, wingbeat frequencies and wing loading correlation

coefficients are highly significant for all groups of insects weighing more than 0.03 grams. In small insects (mass < 0.03 grams) no such relationship was found between wing loading and beating frequency. This suggests that these species are inherently weaker fliers. Several whitefly species examined had mass ranging from 3.3 to 8.0 X 10^{-5} grams, a wingbeat frequency ranging from 165.6 to 224.2 hertz (Hz) (cycles per second) and a wing load from 2.12 to 5.23 X 10^{-3} grams per square centimeter. These data indicate whiteflies are poor fliers and that flight is accomplished through mechanisms such as clap-and-fling wing movement which produce a high drag coefficient.

Weak-flying whiteflies are adrift in abundance during certain periods of the day. Sixty percent of adult whiteflies captured in Isreal was over fallow ground (Gerling, 1984), indicating that flying whiteflies are widespread when populations are high. Byrne *et al.* (1986) recorded similar results in Arizona. Daytime movement is periodic, resembling aphid activity (Johnson *et al.*, 1957). When Byrne and von Bretzel (1987) examined the flight activity of sweetpotato and bandedwinged whiteflies in a cotton-growing region of Arizona, they found a definite rhythmicity. Aerial populations consistently exhibited peaks, with the majority (> 60 percent) of flight activity taking place within approximately the same four-hour period each day. The distinct periodicity of flight might be explained by the fact that adult emergence (> 90 percent) occurs within the first hour after photophase with a teneral period (time of exoskeleton hardening) of slightly more than four hours at 80F (27C).

Whiteflies appear to have evolved behavioral and physiological processes, such as time of emergence and first flight, to minimize mortality during migration. An optimal time of emergence exposes the insects to temperatures which speed certain physiological processes and minimizes the teneral period, when whiteflies are particularly vulnerable because they are unable to fly. In southwestern United States, an optimal eclosion allows the adults to avoid being airborne during the hours of the greatest heat. Dawn emergence appears to afford whiteflies some of the best aspects of both strategies.

A great deal of movement, termed trivial flight by Southwood (1962), takes place within the crop boundary layer. Presumably, insects in trivial flight primarily are searching for feeding and oviposition sites. However, whiteflies are inclined not to leave the plants on which they originate, especially if conditions are favorable for their survival. The extent to which whiteflies fly within a cotton field was examined by Gerling and Horowitz (1984) using flat white sticky traps. They found that traps placed at canopy height caught 17 times more whiteflies on the upper trap surface than on the lower surface. Further, by comparing whitefly capture on traps placed on the ground and at canopy height and by isolating plants near traps using cardboard partitions, they found that all captured whiteflies did not originate upon the plants immediately above the traps.

Gerling and Horowitz (1984) surmised that whiteflies leave cotton foliage due to age-correlated dispersive behavior or in search of better feeding or oviposition (egg laying) sites. Apparently, dispersing whiteflies are attracted to colors of short wavelength (Mound, 1962; Combe, 1982) which results in ascending flight behavior. However, whiteflies in search of better feeding and oviposition sites apparently fly beneath the cotton canopy, as shown in the partition experiment of Gerling and

Horowitz (1984). Whiteflies flying above two yards (two meters) apparently do not recognize host plants before beginning their descent; hence, airborne individuals may land on bare soil. If they happen to reach a plant canopy, they disperse among the plants and search for suitable feeding and oviposition sites (Prokopy and Owen, 1982). If the whiteflies descend to bare ground, they may fly about looking for a proper substrate upon which to land. Apparently, they recognize suitable hosts by color because they tend to accumulate on yellow traps.

Most whitefly movement studies have been conducted within areas where populations inhabited agricultural communities, within which the insects moved freely from plant to plant, crop to crop or weed to crop. Whiteflies also are capable of long-range movement under favorable conditions, but reports of such movement are rare. Once established in an area, whitefly movement appears to be primarily associated with feeding, reproduction and the search for attractive host plants.

SPIDER MITE

Spider mites disperse aerially and by crawling on the plant (Kennedy and Smitley, 1985). Intra-plant movement occurs as pre-reproductive females move to uninfested areas of the plant (Hussey and Parr, 1963; Mitchell, 1973). Inter-plant dispersion occurs in response to environmental and biological cues, such as desiccation of, or damage to, host plants (McEnroe and Dronka, 1971), overcrowding (Boyle, 1957; Hussey and Parr, 1963; Smitley and Kennedy, 1985), increasing predatory activity (Bernstein, 1984), and repellent effects of pesticides (Gerson and Aronowitz, 1981; Iftner and Hall, 1983; Penman and Chapman, 1983; Franklin and Knowles, 1984; McKee *et al.*, 1987). Dispersal behavior of the twospotted spider mite, *Tetranychus urticae* Koch, involves movement up the plant and, if wind is present, orientation away from light and raising of the forelegs (Suski and Naegele, 1966; McEnroe and Dronka, 1971; Boykin and Campbell, 1984; Smitley and Kennedy, 1985). Because of their buoyancy, spider mites can be carried to great heights (Coad, 1931) and for long distances (Johnson, 1969). Thus, there is great potential for spider mite movement from rapidly increasing populations in one crop to another. Such movement has a strong impact on spider mite management (Brandenburg and Kennedy, 1982; Kennedy and Margolies, 1985; Margolies and Kennedy, 1985; Miller *et al.*, 1985).

In the San Joaquin Valley of California, three species of spider mites are key pests of cotton: strawberry spider mite, *Tetranychus turkestani* Ugarov and Nikolski; twospotted spider mite; and the Pacific spider mite, *Tetranychus pacificus* McGregor (Leigh, 1963; Leigh and Burton, 1976; Leigh, 1985). Cotton is plowed under each fall in California and few, if any, weeds remain on which the spider mites can overwinter. Yet, spider mites frequently appear on cotton within one week of its emergence (April-May) and in a relatively random distribution. Colonizing spider mites during the early part of the growing season may be emerging from the soil or moving from nearby weeds. However, it is more likely they are arriving aerially from neighboring crops.

All three spider mite species may be found in an individual cotton field. Surveys of the San Joaquin Valley indicated strawberry spider mite is the dominant species in the early season, with the twospotted spider mite dominant in the mid-season, while the Pacific spider mite is present in 42 to 50 percent of the fields sampled (Grafton-Cardwell *et al.*, 1987). However, when the cotton field is located next to almond orchards, the Pacific spider mite is present in 85 percent of the fields (E. E. Grafton-Cardwell., unpublished data). Thus, perennial plants such as almond act as significant overwintering hosts for spider mites in the San Joaquin Valley. Where cotton is located downwind (or south) of almond, significantly more Pacific spider mites are found in the north half than in the south half of the field throughout the season (E. E. Grafton-Cardwell, unpublished data). Almond appears to serve both as an early season and a continuous host for supplying Pacific spider mites for infesting cotton. Whatever the source, the earliest spider mite colonizers rapidly distribute themselves within and between cotton plants (Carey, 1982; Carey, 1983; Wilson *et al.*, 1983).

During most of the growing season, cotton acts as a recipient of, and not a source for spider mite dispersion. This is because the biological and environmental cues which stimulate large-scale dispersion are not present until the end of the cotton growing season. Since cotton continuously produces new foliage and is usually well irrigated, the problems of desiccation and crowding of the spider mites, characteristics that stimulate dispersal from other crops, do not occur as frequently in cotton. Further, the use of a non-repellent such as the acaracide dicofol (Kelthane®) in cotton does not stimulate the mites to move. The spider mite populations that develop on cotton also tend to inhabit the middle region of the plant through most of the season and the mites are not exposed to wind velocities that would aid in their dispersal (Carey, 1982).

In contrast to cotton, almond trees frequently experience water stress and only produce one set of foliage per season. Since the food source is limited and the almond trees desiccate as a result of water stress, high density spider mite populations shift into a dispersal mode. The occasional occurrence of dense populations of predatory mites may also cause spider mite dispersal from almond. In addition, the acaricides used to control spider mites in almond—propargite (Comite®, Omite®), cyhexatin and hexakis (Vendex®, Torque®) as well as several pesticides used for insects (some pyrethroids and carbamates) are highly repellent to spider mites and stimulate aerial dispersal (Iftner and Hall, 1983; Fisher and Wrensch, 1986; Penman *et al.*, 1986). Thus, almond can be a significant source of sudden, large-scale, aerially dispersing Pacific spider mites and predatory mites throughout the cotton growing season (E. E. Grafton-Cardwell, unpublished data; Hoy, 1982; Hoy *et al.*, 1985). These peaks of dispersion may negatively affect chemical control of spider mites in cotton by increasing the spider mite density above the economic injury level of about seven mites per leaf. However acaricides are usually sufficiently efficacious to reduce spider mites in cotton below the economic threshold.

Many horticultural and field crops, such as melons, beans and corn support high densities of spider mites as they are dried out for harvest (July and August). Although chemical control of spider mites frequently is not required in these crops, drying stim-

ulates spider mite dispersion into neighboring cotton (E. E. Grafton-Cardwell, unpublished data) and causes a second cycle of mite problems in the cotton that may need additional chemical treatments. Spider mites have their greatest impact on cotton in early- to mid- season (Furr and Pfrimmer, 1968), and the late-season dispersion is considered less important. Season influx also is less important.

Defoliation of the cotton at the end of the growing season, and hence the loss of the spider mite food, probably stimulates the mites to disperse and crawl under cover vegetation and the bark of perennials such as almond to overwinter. This may explain why almond may occasionally host an early-season population of dicofol (Kelthane®) resistant spider mites even though dicofol is not used in almond.

PLANT BUG

Several species of plant bugs in the family Miridae that attack cotton appear to be highly mobile with infestations appearing and disappearing within two or three days. Plant bugs usually are seen in the terminals of plants as well as actively flying near sunrise and sunset suggesting a crepuscular (faint light, i.e. daybreak and twilight) flight activity. With the aid of a black light, western lygus bug, *Lygus hesperus* (Knight), can be observed resting and feeding in the terminals of plants at night. When disturbed in the day, adults readily fly but usually to a near plant.

Infestations of cotton by plant bugs are commonly associated with nearby native weed and crop hosts (Smith, 1942). Among the crop hosts of the western lygus bug are alfalfa (Stern *et al.*, 1964) (whether grown for hay or for seed), safflower, (Mueller and Stern, 1974) and beet grown for seed. Weed species in crops, and many native plants such as annual fleabane, *Erigeron annuus* (Pers.), (Fleischer *et al.*, 1987) also serve as hosts for western lygus bug. In arid areas western lygus bug may be a more consistent pest near riparian outflows from mountains. Severity of infestation, often expressed as crop damage, is reported to be greatest in parts of a field that lie adjacent to an alternate host. Schowalter & Stein (1987), Stern *et al.* (1964, 1967) and Sevacherian and Stern (1975) reported that local movement of western lygus bug involves field-to-field movement. Stride (1968) reported a similar relationship between *Lygus vosseleri* Poppham and its native and crop hosts in Uganda. Fleischer *et al.* (1987) stated that movement of the tarnished plant bug, *Lygus lineolaris* (Palisot de Beauvois) from its weed hosts to cotton is largely a diffusion process similar to the flight behavior recorded for the cotton fleahopper, *Pseudatomoscelis seriatus* (Reuter) by W. L. Sterling (Personal communication, W. L. Sterling, Department of Entomology, Texas A&M University, College Station, Texas). We are not aware of any long-range movement studies with plant bugs. However, infestations of the western lygus bug commonly develop in fields in desert areas isolated by several miles from known sources of infestation (T. F. Leigh, personal observation).

Principal natural enemies of mirid plant bugs are several generalist predators including several spiders (Araneida) (Whitcomb *et al.*, 1963; Dean *et al.*, 1987), *Geocoris* spp., *Nabis* spp. and *Orius* spp., bugs and mymarid and euphorid parasites (Clancey,

1968). Species of these natural enemies are found in native vegetation, weed and crop plants used as hosts by lygus bugs (Fleischer and Gaylor, 1987). Movement of plant bug predators and parasites such as *Anaphes ovijentatus* (Crosby & Leonard) and *Leiophron uniformis* (Gahan) (Graham *et al.*, 1986) appear not to be highly migratory since they are localized in the areas with high densities of plant bug host plants.

SUMMARY

A review of the literature pertaining to the short- and long-range movement of insects and mites attacking cotton is presented. The impact of local dispersion between fields, crops and native vegetation is discussed relative to the development of insect suppression techniques. The impact of long range migration by insects between regions acting as source areas and recipient areas is also presented. The discussions point out the need for a thorough understanding of the movement capabilities of cotton pests for developing technologies that require the use of less pesticides and that may be applied on an areawide basis.