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Chapter 8

THE ECONOMIC IMPORTANCE AND CONTROL OF IMPORTED FIRE ANTS IN THE UNITED STATES

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INTRODUCTION

The red imported fire ant, *Solenopsis invicta* Buren and, to a lesser extent, the black imported fire ant, *Solenopsis richteri* Forel have infested, since their introduction in the early 1900s, all, or part of, nine southern states and Puerto Rico. Their spread was enhanced, prior to initiation of a federal-state quarantine in the early 1950s, by concealment of queens or small colonies in nursery stock that was shipped from the original infested area around Mobile, Alabama (USDA 1958). Wherever the imported fire ants (IFA) have become established they have been the source of innumerable complaints from the local residents because of their mound-building, stinging, and feeding habits. These complaints resulted in the promulgation by the United States Congress in 1957 of a federal-state cooperative program for the quarantine, control, and eradication of IFA. Since that time there has been a continuing debate as to the effectiveness and the advisability of such a program. In fact, no consensus has been reached to date on the issue of the economic importance of the IFA, as illustrated by the indeterminant statements on the subject expressed by the various panels of the Symposium on the Imported Fire Ant sponsored by the Environmental Protection Agency and the United States Department of Agriculture (Tschirley 1982). Despite the apparent confusion there is a body of research to draw on and some general conclusions about the economic status of the IFA can be made.

Control procedures for the IFA that utilized various pesticides have also been controversial because of their environmental impact; however, advances in research have revealed several new chemicals that may be used effectively and safely for reducing local IFA population levels, where necessary. In addition new research on pheromones and biocontrol suggests that techniques that are more target specific may become available. These techniques may eventually lead to comprehensive pest management strategies.

ECONOMIC IMPORTANCE

Economics is defined as the management of income and expenditures. Since over $172,000,000 U.S. dollars (U.S. dollars are used throughout this chapter) were spent by federal, state, and other governmental agencies (Canter 1981) for control of the IFA from 1957 to 1981, there can be little question that they are economic pests. The problem comes in defining the actual types of economic losses caused by the IFA. This is further complicated since, in some instances, the ants are actually beneficial. Lofgren et al. (1975) concluded that IFAs affected a broad spectrum of "things," but were not major pests of any one crop or commodity. In the light of some recent findings, this conclusion may be only partially correct. It is apparent that a thorough understanding of the biology and ecology of the IFA is necessary before their economic importance can be judged.

Tschinkel (1982) builds an interesting case for considering IFA as a weed species, but he views them strictly on a theoretical ecological basis that does not consider their place in the practical everyday world. The definition of a weed species is, according to Webster's New World Dictionary, "any undesired, uncultivated plant (or animal), especially one growing in profusion and crowding out a desired crop, spoiling a lawn, etc." When IFA are considered from this perspective, the weed comparison is valid because the IFA are uninvited guests that sting people and their animals, deface lawns, parks, and interfere with farming operations. This view is also too simplistic since imported fire ants are opportunistic, omnivorous feeders who prey on various animal and plant species and thus, depending on the species preyed on, their feeding activity can be beneficial as well as harmful. In fact, if one follows the logic of this argument, we can understand that IFAs 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. It is this point that appears to have been overlooked by many scientists and is the cause of much of the confusion over the pest or nonpest status of the IFA. For example, the literature is replete with examples of beneficial or harmful behaviors attributable to IFAs, but the importance of any one of these cannot be determined without viewing the impact of the ants on the entire life cycle of the parwhere necessary. In addition new research on pheromones and biocontrol suggests that techniques that are more target specific may become available. These techniques may eventually lead to comprehensive pest management strategies.

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Another aspect of imported fire ant biology that relates to their economic importance is the long-term impact of their predation on various fauna. An example of this is a recent report by Mount (1981) that predation by S. *invicta* over a period of 10 to 20 years may be a serious threat to certain ground-dwelling reptiles and birds. The impact of IFA on other ant species has been noted by some researchers (Whitcomb et al. 1972, Roe 1973). Changes of this type can be very subtle, and thus difficult to detect and verify experimentally.

The preceding discussion illustrates the difficulties in making an accurate assessment of economic damages or benefits associated with the IFA. However, with this background, the current knowledge of the economics of IFA behavior can be reviewed with the understanding that the full impact for many of these behaviors has not been determined and other economic behaviors remain to be discovered. The areas of impact can be subdivided into four categories for ease of discussion: (1) public health, (2) agriculture, (3) wildlife and environment, and (4) miscellaneous.

Public Health

Imported fire ant workers are highly aggressive and will attack and sting any animal that disturbs their nest. Persons may also be stung by foraging worker ants away from their nests if they are inadvertently disturbed. The venom consists primarily of alkaloids (2,6-disubstituted piperidines). The identification and synthesis of these compounds has been described by MacConnell et al. (1970). Baer et al. (1977) have shown that the venom also contains a small proteinaceous component with three highly active allergenic antigens.

The typical response to the venom of the IFA follows a predictable pattern (Lockey 1974, James 1976). Initially the venom causes a burning and itching sensation, which accounts for the common name attached to these insects. This is followed immediately by the formation of a wheal and flare that may become as large as 10 mm in diameter. Several hours later, a small vesicle containing a clear fluid develops at the sting site. The vesicle eventually becomes cloudy and a white pustule forms, usually after 24 hours. The pustule is sterile and is a result of the necrotizing effects of the venom alkaloids. If not broken, the pustule remains for a few days to as much as a week. The latter is a special problem for laborers, farmhands, and children since secondary infections may occur.

By far, the most serious potential consequence of the stings is the development of a hypersensitivity reaction to the proteinaceous allergens in the venom. The extreme potency of these allergens is illustrated by Rhoades et al. (1977), who stated that less than 1% of the average volume of venom from the sting (0.07–0.10 μl) is composed of protein. This translates to a maximum protein weight of about 0.001 μg. In comparison, the protein content of the average bee sting is 50 μg.

Numerous cases of severe allergic reactions have been reported (Brown 1972, Triplett 1973, Rhoades et al. 1977, Lockey 1974) and Lockey (1979) cited five fatalities attributable to IFA stings within a period of two years. Rhoades et al. (1977) determined that the incidence rate of new cases for the city of Jacksonville was 3.8 per 100,000 persons per year. However, they considered this figure to be low since it was based only on reports from two allergists who served the city; patients reporting to emergency rooms, general practitioners, etc., were not included in the survey. On the basis of these data, Lofgren and Adams (1982) estimated that at least 1,460 new cases of allergy to imported fire ant venom occur each year. They estimated that the cost of desensitization therapy for these persons at $205,860 per year. Because of the limitations of the survey by Rhoades et al. (1977) it is possible that the number of new cases and cost could easily be twice this estimate. If hyperallergic persons are not desensitized it is imperative that they have ready access to allergy treatment kits.

While systemic allergic reactions are the most dramatic reaction to IFA venom, lesser primary or secondary complications may require medical treatment. For example, Dr. R. F. Triplett conducted a mail survey for the years 1969 to 1971 in Mississippi. In his unpublished survey there were reports of secondary infections, debridements, skin grafts, and amputations.

Clemmer and Serfling (1975) surveyed a total of 240 households (777 persons) by telephone in Metarie, Louisiana. Sting attacks were reported for 29% of the persons during the months of June–August, 1973 and 1.3% required medical consultation. Similar surveys were conducted in Lowndes and Sumter Counties in Georgia. In Lowndes County, Yeager (1978) sampled 156 families, including equal numbers of urban and rural residents. He found that one out of every five residents could expect to be stung each month and less than 5% of those stung required medical care. The Sumter County study (Adams and Lofgren 1981) was conducted in a predominately rural area. A total of 213 sting attacks were reported during one year (1976) on 95 of 272 survey participants (35%). Two individuals (1%) classified their sting reaction as severe, 26 (12%) as moderate, and 183 (87%) as mild.

Adams and Lofgren (1982) reviewed data on patients reporting for medical treatment for arthropod sting or bite attacks at Ft. Stewart, Georgia. IFA were responsible for 161 (49%) of a total of 329 patients treated from April 1 to September 30, 1979. This represents 0.7% of the post population including military personnel (12,000) and dependents (11,000). Only 7% of the sting attacks were caused by bees and wasps. Eight persons (5%) exhibited symptoms of shock due to IFA stings and 11 (7%) developed secondary infections. Five patients were hospitalized for one day each. Direct medical cost for outpatient visits was $24.10 while the cost of hospitalization was $176.45 per day. Total estimated cost attributable to IFA was $5,070.

For purposes of calculating potential medical costs, Lofgren and Adams (1982) used the preceding data to project expenses for the 38.4 million people living in the IFA-infested area. They averaged the sting rates for the studies by Clemmer and Serfling (1975) and Adams and Lofgren (1981) to obtain an average sting attack rate of 32%. Also, they averaged the percentage of persons requesting medical treatment in the Clemmer and Serfling (1975) study (1.3%) and the percentage of the Ft. Stewart population reporting to the dispensary for treatment of IFA stings (0.7%) to obtain a medical treatment rate of 1.0%. Based on these data, the annual cost for medical treatment (one office visit per patient at $23.10) was approximately $2.84 million ($38.4 \times 10^6 \times 0.32 \times 0.01 \times \$23.10$).

Obviously, other research and surveys need to be conducted, but the preceding data indicate that the actual and potential costs to residents of the infested states are significant. Of equal importance is the worry and concern experienced by parents for young children who may suffer severe injury through encounters with IFA in their yards or playgrounds and the constant fear of death endured by those persons unfortunate enough to develop severe allergic reactions to the venom. These fears undoubtedly provide much of the driving force for the continued interest in federal-state programs for wide-scale control of IFA.

Agriculture

Summarized in Tables 8.1 and 8.2 are literature reports of harmful and beneficial environmental interactions of the IFA that affect agriculture. The listings are not intended to be complete tabulations, but major research efforts to document the economic impact of the ants are cited. To realize that these tabulations are incomplete, one needs only to review the papers of Hays and Hays (1959) and Wilson and Oliver (1969), which contain extensive lists of the various food materials (primarily inverte-

TABLE 8.1
Reports of Predation by Imported Fire Ants on Beneficial Insects and Wildlife

Animal	*Impact of Predation*	*Reference*
Invertebrates		
Ground beetle, *Vacusus vicinus*	Significant population decrease	Howard and Oliver (1978)
Carabids, *Galeritula* sp. *Pterostichus chalcites*	Significant population decrease	Brown and Goyer (1982)
Rove beetles, *Oxytelis* spp.	Significant population decrease	Howard and Oliver (1978)
Ants, *S. xyloni, S. Geminata*	Almost completely displaced	Roe (1973)
Various species	Displaced from soybean fields	Whitcomb et al. (1972)
Honeybees, *Apis mellifera*	No data	Wilson and Eads (1949) Cockerman and Oertel (1954)
Ground nesting bees (not identified)	No data	Vinson (1982)
Collembola (not identified)	No data	Morrill (1977), Wilson and Oliver (1969)
Spiders, *Trachelas deceptus*	Significant population decrease	Howard and Oliver (1978)
Lycosa riparia-helluo complex	Significant population decrease	Howard and Oliver (1978)
Unidentified species	No data	Morrill (1977), Reagan (1981)
Isopoda (not identified)	No data	Morrill (1977), Wilson and Oliver (1969)
Annelida (not identified)	No data	Morrill (1977), Wilson and Oliver (1969), Reagan (1981)

Vertebrates		
Six-lined racerunner *Cnemidophorous sexlineatus*	Egg destruction in simulated field tests	Mount et al. (1981)
Chicken turtle, *Deirochelys reticularia*	Ants fed on baby turtles	Mount (1981)
Gopher tortoise, *Gopherus polyphemus*	Hatchlings killed	Landers et al. (1980)
Box turtle, *Terrapene carolina*	One hatchling killed	Landers et al. (1980)
Map turtle, *Graptemys barnouri*	Second year hatchling killed	Mount (1981)
Chameleon, *Anolis carolinensis*	Egg perforated	Mount (1981)
Five-lived skink, *Eumeces fasciatus*	Population decline in Alabama coastal plain associated with IFA	Mount (1981)
Snakes, 7 species	Population decline in Alabama coastal plain associated with IFA	Mount (1981)
Nighthawk, *Chordeiles minor*	Population decline in Alabama coastal plain associated with IFA	Mount (1981)
Ground dove, *Columbigallina passerina*	Population decline in Alabama coastal plain associated with IFA	Mount (1981)
Eastern meadowlark, *Sturnella magna*	Population decline in Alabama coastal plain associated with IFA	Mount (1981)
Bobwhite quail, *Colinus virginianus*	Chicks killed under certain conditions, no evidence of population decline	Johnson (1962)
Cottontail rabbit, *Sylvilagus floridanus*	Penned nestlings killed, no evidence of population decline	Hill (1969)
Wood duck, *Aix sponsa*	Ducklings and pipped eggs destroyed	Ridlehuber (1982)

TABLE 8.2
Reports of Predation by Imported Fire Ants on Pest Arthropods

Arthropod	*Impact of Predation*	*Reference*
Lepidoptera		
Sugarcane borer, *Diatraea saccharalis*	Significant reduction in damaged internodes	Negm and Hensley (1969), Reagan et al. (1972)
Bollworm, *Heliothis zea*	No data	Sterling et al. (1979)
Tobacco budworm, *Heliothis virescens*	Significant egg predator	McDaniel and Sterling (1979) McDaniel and Sterling (1982)
Nantucket pine tip moth, *Rhyacionia frustrana*	Not significant	Wilson and Oliver (1970)
Velvetbean caterpillar, *Anticarsia gemmatalis*	No data	Whitcomb et al. (1972) Buschman et al. (1977)
Greater wax moth, *Galleria mellonella*	No data	Williams (1976)
Soybean looper, *Pseudoplusia includens*	No data	Whitcomb et al. (1972)
Green cloverworm, *Plathypena scabra*	No data	Whitcomb et al. (1972), Snodgrass (1976)
Coleoptera		
Bollweevil, *Anthonomus grandis*	Significant reduction in damaged squares	Sterling (1978), Jones and Sterling (1979), McDaniel and Sterling (1979)
Small southern pine engraver, *Ips avulsus*	No data	Sterling et al. (1979)
Banded cucumber beetle, *Diabrotica balteata*	No data	Sterling et al. (1979)

Pecan weevil, *Curculio caryae*	Significant predation on larvae in simulated field test	Dutcher and Sheppard (1981)
Sugarcane rootstalk borer weevil, *Diaprepes abbreviatus*	Minor predation in simulated field test	Whitcomb et al. (1982)
Alfalfa weevil, *Hypera postica*	Predation in greenhouse tests	Morrill (1978)
Cowpea curculio, *Chalcodermus aeneus*	Significant predation in small field plots	Russell (1981)
Diptera		
Stable fly, *Stomoxys calictrans*	Significant predation on immatures in simulated field test	Summerlin and Kunz (1978)
Face fly, *Musca autumnalis*	Significant predation on larvae in simulated field test	Combs (1982)
Horn fly, *Haematobia irritans*	Significant predation in laboratory and field tests	Summerlin et al. (1977), Howard and Oliver (1978)
Homoptera		
Greenhouse whitefly, *Trialeurodes vaporariorium*	Significant in one greenhouse	Morrill (1977)
Pea aphid, *Acyrthosiphon pisum*	Predation in greenhouse tests	Morrill (1978)
Hemiptera		
Rice stink bug, *Oebalus pugnax*	No data	Sterling et al. (1979)
Green stink bug, *Nezara viridula*	Predation in field cage tests	Kryspin and Todd (1982)
Other		
Striped earwig, *Labidura riparia*	Significant reduction in lawns	Gross and Spink (1969)
Termites, *Reticulitermes* sp.	Large number attacked but not of economic significance	Green (1967), Wilson and Oliver (1969)
Lone star tick, *Amblyomma americanum*	Simulated field studies and surveys	Harris and Burns (1972), Burns and Malancon (1977)

brates) that are harvested, dead or alive, as food. However, these reports on the food habits of IFA do not cite any significant amount of feeding by IFA on plants. This seems strange since IFA require large amounts of carbohydrates in their diet (Williams et al. 1980b). Only one life stage of the IFA (fourth instar larvae) ingests large food particles (Glancey et al. 1981b). Consequently, one would expect that the liquid portion of many foods would be extracted and carried back to the nest in the workers' crop or esophagus. Evidence that this does occur has been obtained recently in studies of IFA feeding on ^{32}P-labeled crops (Smittle et al. 1983, Harlan and Banks 1983, Adams et al. 1983). This research emphasizes the point made earlier in this chapter that the economic impact on any crop must be determined on the basis of the cumulative effects of the IFA throughout growth and harvest. For this review, however, the beneficial and harmful effects are discussed independently.

Harmful Effects

The first effort to document the harmful effects of IFA on agricultural crops was made by Wilson and Eads (1949). They conducted a survey in Mobile, Baldwin, and Washington Counties in southern Alabama that consisted of a systematic poll of 174 farmers and on-site observations of feeding by IFA on various crops. Their direct observations revealed that ants fed on the seeds or seedlings of corn, peanuts, beans, Irish potatoes, and cabbage. According to the farmers polled, the crops most seriously affected were corn, Irish potatoes, soybeans, sweet potatoes, and cabbage. Similar observations of feeding by IFA on various field crops were reported by researchers at a USDA research laboratory located at Mobile, Alabama (USDA 1958). In subsequent years there were few reports of damage to row or cultivated crops; however, there were numerous complaints about IFA infestations of pastures and hayfields.

At least three scientific committees reviewed the IFA problem during the 1960s and 1970s (National Academy of Science, Mills 1967; Council for Agricultural Science and Technology, Anonymous 1976; and the Georgia Academy of Science, Bellinger et al. 1965). All concluded that IFA were not a significant problem in row or cultivated crops. Lofgren and Adams (1982) theorized that lack of complaints of IFA damage to cultivated crops was associated with the extensive use of chlorinated hydrocarbon insecticides in cultivated fields for the control of insects, such as cutworms, wireworms, and white-fringe beetles. They stated that IFA could become a major crop pest following the withdrawal of registrations of chlorinated hydrocarbon insecticides for crop pests by the Environmental Protection Agency in the early 1970s. They concluded that once these compounds were no longer available, residues in the soil would dissipate within a few years and IFA could readily infest the fields.

Evidence for the preceding conclusion occurred in the mid-1970s when farmers in Georgia began complaining about interference of the mounds of the IFA with soybean harvesting operations. Because IFA increase the diameter and height of their mounds in the fall of the year in response to wetter and/or cooler soil conditions, the farmers were faced with either (1) pushing the mounds over with their combines, thus losing some of the beans and risking equipment damage of (2) raising the header bar to avoid impacting the mound tumulus and thus not harvesting all of the beans. Their studies (Adams et al. 1976, Adams et al. 1977) revealed minor losses (< 1 bu per acre; 67.3 kg per ha), although at the time of the study, the loss amounted to $6 to $12 per ha.

Subsequent to these early reports, Lofgren and Adams (1981) noted a greater loss of soybeans than could be attributed solely to interference of the mounds with harvesting. They conducted a series of tests involving eight paired fields of soybeans (one field of each pair was treated with mirex to eliminate the fire ant). At harvest the average reduction in yield of soybeans amounted to 5.86 bu per acre (394 kg per ha) in fields with 20 to 72 mounds per acre (49 to 176 per ha).

Later studies conducted by Adams et al. (1983) and Apperson and Powell (1983) produced results that were consistent with this report. In addition, the study by Adams et al. (1983) presented data that indicated that the majority of the reduction in yield in soybeans could be attributed to destruction of seeds and seedlings by the IFA. However, they also presented evidence that the IFA fed on the growing plants as indicated by the use of ^{32}P.

If these research findings are typical throughout the infested states, the impact on soybean production would be very great. For example, Lofgren and Adams (1982) estimated for 1981 that if (1) 25% of the soybean acreage in the infested states was heavily infested with IFA, (2) the average reduction in yield was 400 kg per ha, and (3) the sale price of soybeans was $0.22 per kg, the total loss of soybeans in 1981 could have been 560,734 metric tons at a value of almost $125 million.

While the effect of IFA on soybeans has received the most attention, research has also been or is being conducted, on other crops. The impact of IFA on citrus in Florida has received considerable attention over the last two years as the potential of IFA damage to young citrus trees has begun to be realized. There had been little prior concern about IFA in citrus groves because until the 1970s they could easily be controlled either with residual chlorinated hydrocarbon insecticides or with mirex bait. In the last few years the population of IFA in citrus groves has literally exploded in some areas of Florida, particularly along the east coast. Brown (1982) reported a loss of more than 50% of the young citrus trees (oranges and grapefruit) in some groves because of IFA. Early reports stated that the trees were killed because the IFA chewed the bark, girdling the trees at or just below the soil surface. Feeding on branches, new terminal growth, flowers, and young fruit has been noted also.

Recent observations indicate that the ants feed on sap oozing from the citrus trees either as a result of mechanical or freeze damage or from direct feeding by the ants. This bleeding phenomenon is most prevalent during periods of warm weather in the winter months. The ants also carry dirt and pack it into these areas of bleeding. This could be a source of infectious plant diseases.

Brown (1982) noted in mature groves that the IFA construct their nests along the drip line of the trees. This causes a problem for fruit pickers since their ladders are usually placed on or adjacent to the ant nests. When the ants are disturbed they crawl onto the ladder and sting the fruit picker. The pickers can also be stung by ants foraging in the tree.

A few instances of damage to corn by IFA have been reported (see Table 8.3). For example, the report by Glancey et al. (1979) involved a situation in which a field had been flooded prior to corn planting. Apparently, IFA colonies floated into the field on flood water. Later, when the farmer planted, the IFA fed heavily on the young corn plants causing a severe reduction in stand and a monetary loss of $4,000 to $10,000. Harlan et al. (1981) demonstrated in greenhouse and field tests that IFA feed on corn plants and, in the case of their greenhouse test, they destroyed large numbers of the seedlings. However, a companion field trial showed only a slight, but significant, reduction in the number of plants and no reduction in corn yield.

Consistent economic damage is caused by IFA to mature okra plants. Feeding by IFA on the flowers of this common southern garden plant has been observed since the early report by Wilson and Eads (1949). Attraction to the okra flowers is so consistent that it can be used as a method for detecting IFA in the field. The IFA feed around the calyx, but some feeding may occur on the pod. In some cases the flower or pod is destroyed but most often the feeding results in a misshapen, scarred, and curved pod with no market value.

The incidence of damage to other cultivated crops has been sporadic, although on the basis of previous findings with soybeans, it would not be surprising if reduction in plant density and yield of other cultivated crops will be found in the future, particularly on some of the minor vegetable crops. For example, Adams (1983) reported on a 20- to 30-acre field of eggplants near Ocala, Florida in which 50% of the plants were destroyed by IFA resulting in a potential estimated crop loss of $56,000 to $90,000. In another instance C. T. Adams and W. A. Banks (personal communication) reported loss of potatoes near Hastings, Florida that was attributable to direct feeding by IFA on the new potatoes.

IFA and their mounds in hayfields and meadows have been the source of consistent complaints since the 1940s and farmers complain of death of newborn calves and pigs in pastures as a result of IFA attacks. This latter behavior is very difficult to document. However, the author has seen piglets being killed by IFA in one instance. Some researchers have theorized that IFA are not a problem in pastures and have attempted to demonstrate that the IFA are beneficial because the mound construction brings nutrients to the surface and creates better soil conditions for the growth of grass (Herzog et al. 1976, Blust et al. 1982).

The problem with the IFA in the hayfields is understandable since, as in the case of soybeans, the mounds interfere with harvest operations. Anyone who has seen a field infested with 100 to 200 IFA mounds per hectare can visualize why the mounds would increase the cost of, and the time required for hay harvest. This is especially true in the heavier, clay soils. In addition, hay bales left on the ground are quickly invaded by IFA, which causes a problem for the field workers. In recent years there is evidence that problems with hay have diminished because of the use of rotary mowers and round balers or hay stackers.

The tending of aphids or scale insects by IFA has been reported for a number of plants including weeds as well as crops (USDA 1958, Wilson and Eads 1949, Wilkinson and Chellman 1979). The latter is the only report that cites actual detrimental effects of this behavior, that is, a 40% reduction in growth of 3-year-old slash pine trees in a grove in north Florida. The wide-spread occurrence of IFA-homopteran associations suggests that other harmful effects may occur.

Beneficial Effects

Since the IFA are omnivorous, it is not surprising that their feeding behavior should have beneficial as well as detrimental aspects. Thus, it is not unexpected that Long et al. (1958) noted that there was an increase in damage by the sugarcane borer (*Diatraea saccharalis*) in sugarcane fields in south Louisiana subsequent to applications of insecticide (heptachlor) for IFA control. Their observations were substantiated by a number of other researchers over the following 15 years and Reagan (1981) reported on a pest management program for a sugarcane borer in Louisiana that depends partially on the predatory activity of IFA. He stated that the sugarcane borer is responsible for more than 90% of all sugarcane crop losses ascribed to insect damage and that losses in sugar yields average 13 to 15% where infestations are not held below the economic threshold. The pest management program ascribes 25% of the control of sugarcane borers to beneficial predators of which IFA are the most important.

In studies in Florida sugarcane fields, Adams et al. (1981) found that

TABLE 8.3
Reports of Economic Damage Caused by Imported Fire Ants

Crop or item affected	*Extent of damage*	*Reference*
Soybeans (germinating seeds and yield)	Extensive (60 to 670 kg/ha yield loss)	Lofgren and Adams (1981), Apperson and Powell (1983), Adams et al. (1983)
Soybeans (interference with harvest)	Moderate (<67 kg/ha yield loss)	Adams et al. (1976), Adams et al. (1977)
Citrus (girdling young trees; annoyance of fruit pickers)	Severe in many Florida groves; many young trees killed; occasional increased cost of picking fruit	Lyle and Fortune (1948), USDA (1958), Brown (1982)
Corn (germinating seeds and seedlings)	Severe in isolated fields	Lyle and Fortune (1948), Wilson and Eads (1949), Glancey et al. (1979)
Hay (mounds interfere with harvest, damage machinery; worker ants invade hay bales)	Moderate	Wilson and Eads (1949), USDA (1958)
Eggplant (maturing plant destroyed; dirt carried onto plant)	Severe in one Florida field (potential loss $56,000 to $90,000)	Adams (1983)
Okra (feeding on flowers and young plants; malformed pods)	Moderate	Wilson and Eads (1949), USDA (1958)
Peanuts (germinating seeds)	Minor	Wilson and Eads (1949)
Potatoes (young plants, tubers)	Minor	Wilson and Eads (1949), USDA (1958), Adams and Banks (1984 pers. comm.)

Sweet potatoes (damage not described)	Minor	Wilson and Eads (1949)
Cotto (damage not described)	Minor	Wilson and Eads (1949)
Strawberries (mounding on plants; tending aphids)	Minor	Wilson and Eads (1949), USDA (1958)
Watermelon (seedlings)	Minor	Wilson and Eads (1949)
Cabbage (seedlings)	Minor	Wilson and Eads (1949), USDA (1958)
Fish (ingestion of ant workers or newly-mated queens)	Moderate in isolated ponds	Crance (1965), Green (1967)
Slash pine (tending scale insects)	Growth reduced 40% in one plantation in Florida	Wilson and Eads (1949), Wilkinson and Chellman (1979)
Longleaf pine (seedlings)	Thirty-three percent of germinating seeds destroyed in test plots	Campbell (1974)
Homes and other buildings (nuisance; consume food)	No estimate	Bruce, et al. (1978), Wilson and Eads (1949)
Air conditioners (electrical shorts and dirt in unit)	Estimate of $1,000 to $15,000 from one firm in Marshall, Texas	Poulan (pers. comm.)
Telephone pedestals (annoyance and damage to equipment)	No estimate	Carlson (pers. comm.)
Airport runway lights (electrical short)	Minor	Lofgren et al. (1975)
Asphalt roads (collapse because of nest excavation under asphalt)	Minor, one area in North Carolina	Grothaus (pers. comm.)
Newborn calves, pigs, and chickens	No estimate	Wilson and Eads (1949), Hunt (1976)

the elimination of IFA with mirex caused a slight but significant increase in damage from sugarcane borer. In contrast to the studies in Louisiana, where the IFA were the only significant ant predator, other ant species were found. They concluded that a multiple predator ant complex was more effective than one dominated by IFA. This research indicates the problem associated with IFA domination of an environment, since they are very competitive and may eliminate or reduce populations of other predatory ants (Whitcomb et al. 1972).

The possible beneficial aspect of IFA for control of the boll weevil in cotton fields was reported by Sterling (1978). He exposed weevil-infested cotton bolls in cotton fields infested with IFA and found that in one set of experiments the ants consumed up to 85% of the weevils, with a weekly average of 60%. Subsequently, Jones and Sterling (1979) reported on another series of tests conducted in east Texas in which they used the chemical exclusion technique to eliminate most of the fire ants from one plot with mirex. Predation by IFA reduced the number of emerging F_1 beetle adults with the result that weevil-damaged squares never exceeded 16.6% through June and early July in the infested plots. At the same time the incidence of weevil-damage squares in the ant-free plot reached a maximum of 38.8%. They concluded from their data that "in some instances, the presence of IFA will result in lower weevil abundance than would have occurred in their absence."

McDaniel and Sterling (1979, 1982) conducted simulated field tests with the tobacco budworm, *Heliothis virescens*, that showed IFA were effective natural predators of ^{32}P-labeled eggs placed on cotton plants. However, they stated that the importance of IFA might be overestimated (1) because the ^{32}P was probably distributed to their nest mates via trophallaxis and (2) the eggs were clumped on the cotton plants and this could have encouraged recruitment of other IFA workers. Despite these problems, it was evident that the IFA were a valuable component of the predaceous arthropod fauna.

Predation by IFA can also affect other components of the predator complex of *H. virescens* as indicated by Lopez (1982) who found that IFA severely affected the survival of the braconid parasite, *Cardiochiles nigriceps*. These data are in contrast to an earlier paper by Sterling et al. (1979), who reported that IFA were very specific predators and failed to reduce entomophagus insect and spider abundance in an agroecosystem. The validity of the data in the latter paper are suspect for a number of reasons, the principle of which are: (1) they used a sampling system that they recognized as having an inherent bias and inaccuracy as to types of insects collected, (2) the numbers of insects collected were so small that it was almost impossible to determine significant differences in the populations between the IFA-infested and free plots, (3) pitfall traps were used only in the IFA-free plot, and (4) the number of ground predators collected, such as rove beetles, ground beetles and earwigs, was insignificant, suggesting that populations of these insects may have already been severely reduced. Brown and Goyer (1982) found evidence for this possibility when they determined that certain species of carabids were reduced significantly in soybean fields by IFA. Since IFA are widespread in distribution and highly competitive for food and living space, they may, over a period of several years, alter the numbers and diversity of other species occupying the same ecological niche. Thus, a census of the fauna of a specific area at some point in time could give the appearance that the IFA are not detrimental when, in fact, they may have already caused changes in the diversity and density of some other animal species.

IFA readily invade cow dung in pastures; thus, it is not surprising that they are predacious on a number of insects that utilize dung for their growth and development. Predation by IFA has been reported on the stable fly, *Stomoxys calcitrans* (Summerlin and Kunz 1978), the face fly, *Musca autummalis* (Combs 1982), and the hornfly (*Haematobia irritans*) (Summerlin et al. 1977, Howard and Oliver 1978).

Harris and Burns (1972) and Burns and Melancon (1977) have reported that IFA are predators of the lone star tick, *Amblyomma americanum*. The latter authors reported significant reductions in populations of the lone star tick in woodland pastures in northwestern Louisiana. However, the overall significance of IFA on tick populations need to be studied in more detail and in a greater variety of habitats. For example, lone star ticks are an important pest on a number of wild animals and are particularly abundant along deer trails. It would be interesting to know if tick populations in these habitats are reduced as significantly as reported for pasture land.

Wildlife and Environmental Effects

Reports of the effect of fire ants on wildlife date back to the late 1930s when there were reports of *Solenopsis geminata* being predacious on the nestlings of the bobwhite quail. Reports of this type were also noted for the IFA in the late 1940s by Wilson and Eads (1949) and USDA (1958). During the 1960s and 1970s most wildlife experts viewed IFA as of little importance on bobwhite quail or other types of wildlife. During the past 20 years the author has heard numerous reports of IFA attacks, primarily on ground-nesting birds. However, the relative importance of isolated instances of predation by IFA cannot be judged by reports of this type.

Recently, Mount et al. (1981) provided data on predation of IFA on eggs of a lizard, *Cnemidophorous sexlineatus*, and Mount (1981) made general observations on population levels of vertebrates in the Alabama coastal plains. He suggested that long-term predation by IFA may be reducing natural populations of a number of vertebrates and that a lapse of 10 to 20 years is necessary between the time an area becomes heavily infested and the time the impact of the IFA becomes obvious to the field naturalists. The most striking declines in populations have occurred among some species of snakes and lizards, particularly five-lined skinks.

Aside from declines in populations of lizards and snakes, Mount (1981) also reports observations of another biologist who concluded that populations of the nighthawk, the ground dove, and the eastern meadowlark have declined in the Alabama coastal plain, but not in northern Alabama.

Predation by fire ants on ducklings and pipped eggs of the wood duck was reported by Ridlehuber (1982) in 3 of 20 nest boxes located in east-central Texas. Observations of natural cavities in trees over land showed that 14 of 20 sites (70 percent) were visited regularly by ants. None were used as nesting sites by wood ducks.

Miscellaneous Effects

This section is included to provide illustration of the versatility of the IFA in causing problems for man. IFA are known to sporadically invade homes and other buildings on occasion, mostly in search of food or water (Bruce et al. 1978). An example of the potential problems associated with IFA in buildings is the fact that during the writing of this chapter the air-conditioning system in the author's building was inactivated twice because IFA invaded the electrical control box.

As minor as this problem may seem, it did involve the expenditure of time and money since a maintenance man was required to correct the problem at a labor cost of about $15. If the problem had occurred in a private residence or business the owner might also have had to pay a service charge of $20 to $30. If situations of this type occur throughout the infested area, one could easily assume that thousands of dollars are spent each year on similar "simple" problems. A recent report by one firm in Marshall, Texas estimated $1,000 to $1,500 in business attributable to IFA damage to air conditioners (H. K. Poulan personal communication).

Another consistent complaint has been the invasion of telephone pedestals by IFA (D. Carlson, personal communication). These pedestals are used for various connections or linkings of telephone cables or wires in the field. There are literally thousands of these units located throughout the south. Two problems are associated with IFA in the pedestals. First, the telephone maintenance people may be stung when they attempt to work within the pedestal, and second, the IFA may damage the equipment.

Two other isolated problems have been reported. Lofgren et al. (1975) cited a report of the inactivation of airport runway lights in a manner similar to the air conditioner incident. R. Grothaus (personal communication) noted damage to asphalt roads in and near Camp LeJeune, North Carolina, This problem was discovered on a few secondary roads where the IFA tunneled underneath the asphalt and removed sufficient dirt so that a small portion of the road collapsed.

CONTROL OF IMPORTED FIRE ANTS

Historically, control of various ant species has relied on chemicals and, more specifically, the combination of a chemical toxicant with an attractive food material to form a toxic bait. The efficacy and desirability of this approach rely on the fact that control of an ant colony ultimately depends on the death of the queen. In most cases the worker population of the colony may be reduced drastically, but the colony will survive and multiply if the colony queen survives. The prime requisite of any effective toxic bait is a chemical with a delayed toxic or physiological activity. Toxic compounds that affect the foraging ants too quickly prevent them from returning the bait to the colony and distributing it to their nest mates and queen.

While toxic baits have been the preferred approach to IFA control in recent years, control in the 1950s and the early 1960s relied heavily on the use of residual or contact insecticides such as chlordane, heptachlor, and dieldrin. These compounds were used extensively for IFA control, either as aqueous drenches for individual mounds or as granular formulations applied as residual treatments over large areas. It was the use of these chemicals in the federal-state IFA control program (promulgated by the U.S. Congress in 1957) that incited much of the controversy over IFA control in the late 1950s. During the period from 1957 to 1962 thousands of acres were treated at application rates ranging from 0.25 to 2 lb per acre (0.11 to 0.91 kg per ha). These treatments resulted in numerous reports of adverse environmental effects to a variety of organisms. Consequently, the development of mirex bait by the USDA in the early 1960s (Lofgren et al. 1964) was hailed as an outstanding development since it appeared to provide a means to control IFA over large tracts of land with minimal environmental effects. Mirex bait consisted of a granular carrier (12–30 mesh corncob grits) onto which a food attractant (soybean oil) containing the toxicant mirex was absorbed. While several variations of the formulation were tested, the most extensively used bait contained 0.3% mirex, 14.7% soybean oil, and 85% corncob grits (Banks et al. 1976). The bait was applied with ground or aerial equipment, usually at the rate of

1.25 lb per acre (1.36 kg per ha). At this rate the actual application rate of the toxicant, mirex, was 4.2 per ha.

In 1968 a study was initiated by the USDA and cooperating states to test the feasibility of eradicating IFA with mirex bait. The results of these studies (Banks et al. 1973) revealed that eradication might be technically feasible since no insurmountable technical problems were detected. Coincident with these studies other problems arose with regard to the use of mirex. It was discovered that even though extremely small quantities of the toxicant were applied (4.2 per ha), residues could still be detected in a large number of nontarget organisms (Markin et al. 1974). Eventually, residues were also detected in adipose tissue from humans (Kutz et al. 1974) and laboratory studies suggested that mirex might be a carcinogen (Ulland et al. 1977). The final result was that mirex bait registrations were cancelled by the Environmental Protection Agency in December of 1978.

With no adequate bait formulations available for control of IFA, a number of investigators began to evaluate the potential of other methods, particularly the treatment of individual mounds or colonies of IFA with chemicals (Morrill 1976, Hillman 1976, Williams and Lofgren 1983) or hot water (Tschinkel 1980). Over the next several years a variety of chemicals were tested and registered as mound drenches or fumigants (Williams and Lofgren 1983; Metcalf et al. 1982).

The primary objective in the application of mound drenches and injection or fumigant treatments is the rapid exposure of the ant population within the mound to the chemical. While this may sound simple, a variety of factors can influence the effectiveness of the treatments including soil type, soil moisture content, temperature, and mound height and shape. Of primary importance is the need to kill the colony queen. Killing thousands of worker ants will only result in a temporary abatement of the colony growth since the surviving workers will move the queen, and any remaining brood, to a new location, where they will rapidly begin development again. Another important factor is the percentage of the worker ants that are away from the nest at the time of treatment. Normally, these ants will not return to the nest when it has been contaminated with insecticide, but will establish satellite queen-less colonies. These may persist for many weeks unless they are also treated.

IFA construct the largest mounds when the soil is wet and/or cool. Thus, the colonies and queen should be easier to kill at this time. In contrast, IFA mounds are not maintained well during hot, dry weather and in sandy soil and they may become flattened, dispersed, and irregularly shaped. At this time the ants move deeper into the soil to obtain a favorable temperature and moisture environment. Obviously, it is more difficult to contact the workers and queen at this time. Probably the best advice for utilization of mound drench treatments is to follow directions on the label, use common sense, and re-treat new or satellite colonies as needed. Finally, mound treatments are labor intensive and thus have limited usefulness in alleviating IFA problems over large areas.

Efforts to develop chemical formulations that could be applied as residual area treatments for cropland similar to the granular formulations of the chlorinated hydrocarbons that were used in the 1950s have been unsuccessful (Sheppard 1982, Stringer et al. 1980, Banks et al. 1982). The USDA began an accelerated search for delayed-action toxicants in the mid 1970s to replace mirex for fire ant bait control. Williams (1983) reported the evaluation of more than 5,000 chemicals. Twenty-nine compounds were tested in baits; however, only one was developed commercially. This compound was an amidinohydrazone (AC 217,300; tetrahydro-5,5-dimethyl-2(1H)-pyrimidinone, [3-[4-(trifluoromethyl)phenyl]-1-[2-[4-(trifluoromethyl)phenyl]ethenyl]-2-propenylidene]hydrazone). The chemical was formulated at concentrations of 2.5 to 10% in a bait consisting of extruded corn pellets and soybean oil. It proved to be very effective against laboratory colonies consisting of a queen, immatures, and 10,000 to 100,000 workers. In every case either the entire colony was killed or most of the workers and the colony queen were killed (Williams et al. 1980a). Subsequently, Banks et al. (1981) reported that AC 217,300 formulated with soybean oil on an extruded corn pellet bait was quite effective in controlling natural populations of IFA in large-scale tests. Conditional registration of AC 217,300 in a bait called Amdro® was approved by the EPA in 1980 for use against IFA in pasture, range grasses, lawns, turfs, and nonagricultural land. The bait is similar to that tested by Banks et al. (1981) and contains 0.88% AC 217,300. It is registered for broadcast application at 1 to 1.5 lb per acre (1.12 to 1.68 kg per ha) or 4 to 6 g AI per acre (9.85 to 14.78 g per ha). Full registration of this bait to include application to agricultural crops has not been received to date.

Other older compounds, such as boric acid, are registered for ant control and may be useful in homes. Boric acid is known to be moderately toxic to IFA, but the necessity of using water-based sugar formulations limits its usefulness for large-scale outdoor application.

While standard toxicants provide the most effective and rapid approach to IFA control by affecting all colony members, including the queen, compounds that inhibit reproduction can also cause death of the colony. Thus, chemicals that interfere with larval development or the ability of the queen to lay eggs will ultimately kill the colony. The undesirable aspect of this approach is that the workers in the colony are not affected and remain a problem. Workers that lose their queen cannot replace her by feeding special food to some larvae, as is the case with honey bees. There is the possibility that orphaned workers will adopt a new fertilized queen following mating flights from other colonies (Tschinkel and Howard 1978) although evidence that this occurs to any extent in the field is lacking. Also, queen adoption is dependent, at least partly, on production of the queen recognition pheromone, which occurs about two weeks after their dealation (Glancey et al. 1981a).

The first actual utilization of the reproduction inhibition approach was presented by Edwards (1977) and Hrdy et al. (1977). They demonstrated control of populations of the pharoah ant, *Monomorium pharaonis* (L.) in buildings with applications of baits of two juvenile hormone analogs, hydroprene and methoprene. Vinson and Robeau (1974) and Banks et al. (1978) demonstrated that IFA colonies in the laboratory could be killed with Stauffer MV-678 (1-(8-methoxy-4,8-dimethyl-nonyl)-4-(1-methylethyl)benzene) and JH-25 ((E)-1-[7-ethoxy-3,7-dimethyl-2- octenyl)oxy]-4-ethyl benzene. Subsequently, Banks and Schwartz (1980) reported on field tests in which 76% of the IFA colonies were destroyed with a soybean oil bait of Stauffer MV-678. In other unpublished data 85 to 90% control of IFA has been obtained following two aerial applications of baits of Stauffer MV-678 made with soybean oil and pregel defatted corn grit.

Other IGRs that have shown promise against IFA are: Ciba-Geigy CGA-38531, 1-(3-ethoxy butoxy)-4-phenoxybenzene; Montedison JH-286, 1[(5-chloro-pent-4-ynyl)-oxy]-4-phenoxybenzene; and Maag Argochemicals RO 13-5223, ethyl[2-(p-phenoxyphenoxy)ethyl]carbamate (Banks et al. 1983). The latter compound is under commercial development and has been assigned the tradename Logic®.

Lofgren and Williams (1982) reported on a novel chemical for control of IFA (avermectin B_1a) that acts as a highly potent inhibitor of reproduction by queens. Avermectin B_1a is a natural product derived from a soil microorganism, *Streptomyces avermitilis*. In laboratory tests, concentrations as low as 0.0025% in soybean oil completely stopped reproduction by the queen. In field tests worker brood was found in only 8 of 928 colonies that had access to baits applied at rates ranging from 0.0077 to 7.41 g per ha. Glancey et al. (1982) found that avermectin B_1a causes irreversible cell and tissue damage to the ovaries of the queen. The damage is characterized by atrophy of the squamous epithelium that shields the ovarioles and pycnosis of the nurse cell nucluei. This physiological damage results in complete or partial reduction in the number and size of eggs laid. Commercial development of this compound is being conducted under an experimental use permit from the EPA. The bait formulation is called Affirm®.

The current status of biocontrol of IFA has been reviewed by Jouvenaz et al. (1981). Populations of the IFA in the United States appear to be disease free (Jouvenaz et al. 1977). However, two Microsporida and a neogregarine have been recovered from populations in South America. The most common species, *Thelohania solenopsae*, was found in 25% or more of the colonies examined at the end of the rainy season, but much lower infection rates (about 5%) were noted at the end of the dry season (Jouvenaz et al. 1980). An undescribed microsporidian was also detected that infected a much lower percentage of the colonies. The neogregarine, a *Mattesia* species, was found in a small number of colonies. Virus-like particles were discovered in an undescribed *Solenopsis* species from Brazil and a bacterial infection was found in one colony of *S. invicta*. The importance of all of these organisms in limiting populations of IFA in South America has never been determined.

Three groups of parasitic arthropods are known to affect IFA. *Solenopsis* (formerly *Labauchena*) *daguerri*, a workerless social parasitic ant, has been thoroughly studied (Silviera-Guido et al. 1973). This species has been found in association with *S. richteri* in Uruguay. The queens "yoke" themselves to the IFA queen permanently by grasping her between the head and thorax. The IFA workers care for the parasitic queen and her progeny preferentially, reducing the vigor of the IFA colony. While high incidences of parasitism (30 to 40%) have been found in some areas in Uruguay, the rate is about 4% in most locations. No instances of these social parasites attacking *S. invicta* has been reported (Jouvenaz et al. 1981). The other two groups of parasites associated with fire ants in South America are eucharitid wasps (*Orasema* sp.) and phorid flies of the genera *Pseudacteon* and *Apodicranea*. The life cycles of these parasites have been studied by Williams (1980), but their importance for IFA control has not been determined.

Various nonspecific predators of IFA queens, workers, and larvae have been studied in the United States. Again the true significance of any of these is undetermined, but there can be little question that newly mated queens are very vulnerable to predation. Buren et al. (1978) suggested that manipulation of predators of newly mated queens could lead to an effective method of pest management for IFA. However, this possibility appears remote when considering the changing population and agricultural trends in the southern United States and the potential for IFA to invade and populate disturbed habitats. Certainly increasing needs for food production and living space for man will continue to provide disturbed or altered habitats that will favor IFA queen survival over that of the nonspecific predators.

The greatest possibilities for biocontrol of IFA appear to remain undiscovered in South America. Hopefully, specific diseases or parasites of IFA will be detected when future research efforts are made in this direction. Behavioral chemicals may be useful for IFA control (see Chapter 7) but as yet none have proven effective.

The overall goal for IFA control should be an integrated pest management program incorporating all the preceding procedures. This goal will not be achieved until much more research is accomplished on nonchemical control methods, particularly the search for, and development of, biological control agents in the homeland of the IFA in South America.

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