10

An Insect Pest of Agricultural, Urban, and Wildlife Areas: The Red Imported Fire Ant

John H. Klotz, Karen M. Jetter, Les Greenberg, Jay Hamilton, John Kabashima, and David F Williams

Introduction

The red imported fire ant (RIFA), *Solenopsis in*victa (Buren), is an insect pest of particular importance in California due to its potential impact on public health, agriculture, and wildlife. In 1997, RIFAs hitchhiked to the Central Valley on honeybee hives brought in from Texas for pollination of an almond orchard (Dowell et al. 1997). There has been local spread from these locations to surrounding irrigated areas. In 1998 the ants were detected in several other locations, including an area covering at least 50 square miles of Orange County. As a consequence, all of Orange County, parts of Riverside County between Palm Springs and Indio, and one square mile of the Moreno Valley were quarantined. The size and distribution of the infestations indicate that the RIFA has been established and spreading for several years in southern California.

The RIFA has both beneficial and detrimental effects on our environment. In a few cases they are predators of agricultural pests, but mostly they have a negative impact. Their large mounded nests, which can be 35 cm (1.1 feet) high, damage mowing and harvesting equipment. When people or animals disturb their nest, the highly aggressive ants swarm out and attack and sting the unwary intruder. In some cases people hypersensitive to their venom have died.

They are attracted to irrigation lines during times of drought, plugging sprinkler heads and chewing holes in drip systems (Vinson 1997). Their aggregation near electrical fields (Slowik et al. 1996) can result in short circuits or inter ference with switches and mechanical equipment such as water pumps, computers, and air conditioners. More serious problems can arise when they infest traffic signals and airport runway lights (Lofgren et al. 1975).

Biology and Ecology

The RIFA is the most thoroughly studied ant. It has been the focus of research and control efforts for more than four decades (Williams 1994). Comprehensive reviews on their biology and ecology can be found in Vinson and Greenberg (1986), Vinson (1997), Taber (2000), and for California, Greenberg et al. (1999, 2001).

Fire ants undergo complete metamorphosis in their life cycle, which consists of four stages: egg, larva, pupa, and adult. The queen lays hundreds of eggs each day. After 7 to 10 days the eggs hatch into larvae. In another one to two weeks the larvae molt into a quiescent pupal stage. Pupae resemble curled-up adults and cannot move. Over the next one to two weeks the pupae acquire the reddish-brown pigmentation of adults. In the final molt, female pupae become either adult workers or reproductives. Mature colonies of RIFAs have 200,000 to 300,000 workers, and either one queen (monogyne) or many queens (polygyne).

Monogyne colonies are territorial and reproduce by mating flights. The males die after copulating, while the newly mated queens seek out nest sites. Fire ants are not strong fliers, but can fly several miles before landing. They are attracted to reflective surfaces such as pools and truck beds where they will land, and in the lat ter case, sometimes be transported for hundreds of miles. In the more typical case a newly mated queen lands on the ground; removes her wings, and then searches for moist, soft soil where she digs a small hole. Inside the hole, she seals the entrance and begins laying eggs. After one or two years the colony matures, and large numbers of winged reproductives (alates) are produced in preparation for mating flights in spring. These nuptial flights can occur at other times if conditions are favorable. Alates prefer to fly after it rains, on warm, clear days with no wind.

Polygyne colonies are not territorial and may consist of many mounds. As a result, they are larger than monogyne colonies and have higher mound densities. Polygyne infestations have hundreds of mounds per acre, whereas monogynes have 30-40. In addition to mating flights, polygyne colonies can also spread by fission or budding (Vargo and Porter 1989), an adaptation that may allow them to invade areas where conditions are not favorable for mating flights.

RIFAs can, and do, fly almost any time of the year in California (Les Greenberg, personal observation). Instead of rain being the triggering event for a flight, water from sprinklers is. adequate. To be successful, though, mating flights must be coordinated over large areas so that males and females from different colonies can form large mating swarms hundreds of feet above the ground. In addition, whether an infestation is monogyne or polygyne is useful information, because the latter with larger and more numerous colonies will have more frequent and intense interactions with people.

The RIFA has an omnivorous diet and opportunistic feeding habits. They will feed on any plant or animal they encounter (Lofgren et al. 1975). Their primary diet, however, is insects and other small invertebrates (Vinson and Greenberg 1986), including some that are pests of important agricultural crops such as the cotton boll weevil (Sterling 1978); sugar cane borer (Reagan 1981), and tobacco budworm (McDaniel and Sterling 1979, 1982). They are also scavengers and feed on carrion.

In heavy infestations RIFAs saturate the environment and become the dominant ecological force. As 'a consequence, coexisting species of ants, other invertebrates (Porter and Savignano 1990), and vertebrates (Lofgren 1986) suffer and are sometimes eliminated. The negative effects of RIFAs on invertebrate and vertebrate biodiversity in the South are extensive (Wojcik et al. 2001).

Their notoriety, of course, is due mainly to their aggressive defense of the nest accompanied by their painful sting, which they are able to inflict in unison after crawling up the legs of an unwitting victim. In order to sting, they must first grab the skin with their mandibles for leverage, and then curl their abdomens to insert the stinger. The venom contains piperidines, which cause a burning sensation, and proteins, which can cause life-threatening anaphylactic shock in a small percentage (< 1 percent) of the population. Their sting causes a white pustule to form on the skin.

Introduction and Spread

The RIFA originates in lowland areas of South America and was most likely introduced into the United States between 1933 and 1945 (Lennartz 1973). The initial colonization in Mobile, Alabama probably occurred as a result of infested soil from South America used as ship ballast or dunnage, and dumped at the port. At that time several native fire ant species thrived in the southeast and the presence of another exotic one created little concern. But by the 1950s their rapid spread and aggressive nature alarmed the public. Now they inhabit all of the southern states from Florida to Texas and as far north as southern Oklahoma, Arkansas, Virginia, and Tennessee.

Since their first documented interception at a border station in California in 1984 (Lewis et al. 1992), RIFAs have been found in several counties. The first outbreak was discovered in Carpinteria in Santa Barbara County in 1988 and was eradicated (Knight and Rust 1990). Recent outbreaks are more serious because they are not confined to a single location and may have gone undetected for three to five years, giving the ants time to spread. Outbreaks are associated with commerce, with the ants arriving on trucks, trains, or other vehicles. A partial list of likely sources includes the root balls of nursery stock, sod, dirt attached to honeybee hives and encrusted on land-moving equipment, and produce brought into the state. New housing developments, with their inflow of building materials, trees and plants, and dirt-moving tractors, are especially vulnerable.

Since the 1997 outbreak in Kern County, more extensive infestations have been found in Orange and Riverside counties, but it is not known how they were brought in. Additional isolated infestations have been found in San Diego, San Bernardino, Los Angeles, Fresno, Madera, and Stanislaus counties. Commerce from infested states will continue to bring imported fire ants into California.

There is no way of predicting how far the RIFAs will spread in California, but if their history in the South is any indication, their future distribution in California could be extensive. Two factors are critical to their survival: temperature and moisture. A map of the expected distribution of the RIFA in the United States based on a 0° minimum temperature shows them inhabiting the entire West Coast from southern California to northern Washington (Killion and Grant 1995). Water, however, is a limiting factor in many areas in southern California.

The arid climate of southern California's inland deserts is inhospitable to RIFAs. But due to irrigation the RIFA became established on golf courses, nurseries, horse facilities, and turf farms in the Coachella Valley. Flood irrigation can even spread the RIFA because they form rafts of living ants that are carried by the water to new locations. The queen and brood are within these rafts, so a new mound can spring up instantly wherever they touch land. As soil conditions become dry, the RIFA will move its nest to an area with more moisture, such as around homes, irrigated farmlands, watering holes on rangelands, and near lakes, ponds, and streams.

Another factor that may limit or slow down its spread in California is competition with other species of ants. In southern California, for example, there are reports of intense interspecific competition between the RIFA and the Argentine ant, *Linepithema humile.* In the South, reinfestation of treated areas by the RIFA is common because control measures often eliminate other species of ants that are competitors (Williams 1986).

Intervention Strategies

There are three levels of policy action that address the RIFA threat: (1) prevention of their ,entry into the state, (2) quick eradication of outbreaks, and (3) containment and management if they become established. Policy options designed to prevent their entry range from government inspections and monitoring to quarantines on the importation of agricultural commodities that may harbor stowaway RIFAs.

Once an outbreak of RIFAs is discovered, eradication should be attempted as soon as possible. The longer the time lag between surveys to map infestations and the initial treatment, the more time the ants have to spread. As the RIFA spreads in all directions into surrounding areas, survey and treatment costs increase exponentially with the elapsed time between infestation, detection, and eradication. Eradication efforts in the South have failed due to reinfestation by RIFAs from surrounding untreated areas.

The situation is different in California because the outbreaks are localized and surrounded by inhospitable nonirrigated land. Consequently, eradication is a realistic policy choice for controlling the RIFA in California. Small, discrete infestations in California have been successfully, eradicated. In addition, new, highly effective insecticides such as fipronil will soon be available in California for use against the RIFA (Chris Olsen, Aventis, personal communication 2002). Registration has been approved by EPA and is pending in California. Currently, eradication can only be completed with chemical treatments, including baits and contact insecticides.

To address the fire ant crisis, the California Department of Food and Agriculture (CDFA) developed a short-term interim plan to deal with the immediate problem and a long-term control plan to prevent future infestations if current eradication efforts are successful. Both plans were developed with the aid of the RIFA Science Advisory Panel, a group of university and U.S. Department of Agriculture (USDA) fire ant experts.

The interim plan was announced in March 1999 and called for treatment to begin in April 1999. Beginning in July 1999, treatment programs are coordinated by CDFA through contract agreements with local agencies. Funding is through $40 million in budget commitments by the state legislature and California Governor Gray Davis. The money is available over a fiveyear period. In 2004, the eradication program will be reevaluated for feasibility. Objectives of the interim plan include limiting the local spread of the RIFA and training personnel in local agencies on proper identification and treatment of fire ants. To coordinate eradication efforts, the CDFA developed a treatment protocol for county administrators. The protocols include: (1) pest identification; (2) detailed location of RIFA mounds; (3) surveys of local areas to find additional mounds; (4) application of a metabolic inhibitor (hydramethylnon) and an insect growth regulator (pyriproxyfen or fenoxycarb) in granular bait form when soil temperature is between 65° and 90°F and free of rain or irrigation for 36 hours (the protocol allows for the use of insecticide drenches if reproductives are found); and (5) a visual and bait survey of treated mounds six weeks after the insect growth regulator application. If RIFA mounds are found on private property, the protocol requires the owner's permission before a treatment can be applied.

The interim plan also contains a protocol for surveys in areas where an infestation is suspect= ed and one for monitoring to assess efficacy of a treatment. It specifies how long monitoring should continue and how visual monitoring of bait stations should be conducted in different areas such as orchards, golf courses, and parks. Treatments may be undertaken by city, county, state, or federal agencies, but should be reported to the CDFA. In conjunction with the interim plan the California Environmental Protection Agency's Department of Pesticide Regulation will be monitoring the impact of the insecticides on the environment.

In addition, the CDFA has developed the California Action Plan for RIFA. This comprehensive plan supplements the interim plan with public outreach efforts to inform and train local agencies on the protocols described in the interim plan. The state will coordinate multicity programs, but actual treatment will be administered by local agencies. The action plan also calls for monitoring industries that have a high risk of transporting the RIFA to new locations. Quarantines will be used to slow the spread of RIFAs when new infestations are found.

Surveillance for RIFAs at California's inspection stations will be strengthened. The exterior quarantine improvements include an additional inspector for each work shift at southern border inspection stations to improve the detection of RIFAs on high-risk vehicles, new inspection stations and 10 new inspectors, and research into rapid identification techniques for RIFAs.

The state will also employ biologists to survey high-risk areas for RIFA infestation. Research funds will be made available for studies on the optimal treatment of the RIFA under California's unique conditions. The goal of the California Action Plan is to eradicate or control the spread of RIFAs in 5 to 10 years. If eradication is successful, surrounding areas will need to be surveyed for at least i year. Since newly mated females can travel several miles, the monitoring and survey area should. be at least three miles around the eradication zone. If eradication efforts fail, the current plan would form the foundation of future management programs and another set of policy decisions would need to be made regarding the scope of public expenditure for containment and management of the RIFA. Another option would be to stop public management measures, allowing the RIFA to spread and establish itself throughout its climatic range in California.

Parties Affected

The RIFA is unique among California's exotic pests because of its potential impact on so many aspects of the state's economy. They pose a threat to homeowners, growers, and wildlife with their sting, their direct damage to crops and livestock, their interference with electrical and irrigation equipment, and their ability to displace native species.

The RIFA prefers to nest in soil in open, sunny areas, but it can be a serious household pest (Klotz et al. 1995). For homeowners the potential problems include medical treatment for stings, interference with communications and electrical equipment, direct and indirect costs (such as environmental degradation) of increased pesticide use, and reduced use of recreational facilities. In infested areas, picnics and recreation involving ground contact are avoided, especially around lakes. Many homeowners become frustrated by their inability to keep their lawns free of fire ant mounds. Children avoid going barefoot or playing in yards that are infested with RIFAs, and gardening. activities are curtailed. The fear of being stung has even led to liability considerations and reduced property values (Vinson 1997).

Agriculture in southern states has been significantly damaged by fire ants both directly through lost production and indirectly through economic losses from quarantines. The RIFA feeds on many crops, including the seeds or seedlings of corn, peanuts, beans, Irish potatoes, cabbage, and young citrus. Their mounds often interfere with harvesting equipment and reduce usable pasture. They cultivate and defend plant lice from predators, thereby interfering with biological control. They can cause blindness and death in livestock as well as diminish the overall quality of livestock. The painful stings are a nuisance to farm laborers, and RIFAs can cause automatic feeding and irrigation systems to malfunction. Quarantines impose additional costs, because hay, equipment, beehives, and nursery products must all undergo special treatments to meet regulations.

In the South, RIFAs reduce invertebrate and vertebrate biodiversity and threaten endangered species (Wojcik et al. 2001). They inflict damage on ground-nesting reptiles, birds, and mammals, especially their newborns. Their foraging efficiency is such that other species of ants, invertebrates (Porter and Savignano 1990), and vertebrates (Lofgren 1986) are eliminated. In addition, many chemical control measures for RIFAs adversely affect wildlife. In California, similar negative effects may occur in lowland and coastal wilderness areas if the RIFA becomes established.

Policy Scenarios

The policy options for managing RIFAs are either eradication or allowing it to become established and then imposing private controls and quarantines. The expected costs to taxpayers of a public eradication program will be compared to the expected benefits to households and agricultural industries if establishment is avoided.

The CDFA eradication program has been funded for 5 years, with the possibility of another 5 years, depending on progress, for a maximum of 10 years. Taxpayer funding for the RIFA eradication program is fixed for the 5year period and has not changed in response to the discovery of new infestations. Because a biological risk assessment has not been done, the probability of success for the eradication program has not been estimated. Therefore, the cost/benefit analysis will determine the probability of success needed for the expected benefits to be at least as great as the expected costs. This probability will be estimated for a 5-year eradication program, a 10-year eradication program, and two 5-year programs.

While containment is another policy option, the lack of knowledge on how the RIFA interacts with the California environment prevents us from making any meaningful biological or economic risk assessments of possible strategies. However, a policy of containment to slow the spread of RIFAs would be important to consider should eradication efforts fail.

Economic Analysis

Eradication Costs

Eradication costs are incurred by taxpayers and nurseries within quarantined areas. Taxpayers pay the regulatory agency costs of implementing the interim and long-term action plans. As part of any eradication program all nurseries and infested golf courses within the quarantine area must treat their premises for RIFAs, earthmoving equipment must be free of soil, and other restrictions met. The total cost of the eradication program in this study will be the cost to taxpayers of the public project, plus the costs to nurseries and other businesses to comply with quarantine regulations. Insufficient data are ,available on the number of golf courses in the affected areas. Consequently, those quarantine compliance costs are excluded from the analysis. Treatment on land around private residences is done through the public project.

The current 5-year public funding level of the RIFA eradication program is $40 million. This includes $8.4 million for the first year, $7.4 million a year for the remaining 4 years and an additional $2 million general allocation. We assume that the annual funding level for the next 5-year period is also $7.4 million a year, with no other allocations or increases in funding.

The cost to nurseries is calculated as the amount of acreage affected times the treatment and monitoring costs per acre. The amount of acreage that is affected in the quarantined areas is equal to the total nursery acreage in Orange County, plus 10 percent of the acreage in Los Angeles and Riverside counties. Total affected acreage is 2,300. At per acre treatment costs of $650, total private costs are $1.5 million a year. Total annual private and taxpayer costs are $8.9 million.

The present value of the initial 5-year project is $39.4 million when discounted at a longterm interest rate of 7 percent. Should the eradication project require an additional 5-year period, the present value of taxpayer and private costs for the second 5-year period is $26 million. In total, the present value of the 10-year project is $65.4 million.

Establishment Costs

Households, agriculture, and wildlife are all affected by RIFA. However, the costs and benefits of the RIFA spreading throughout California would not be evenly distributed among these groups. Some households, farms, or ranches may suffer from large infestations and costs, while nearby homes and agricultural operations may have little or no damage. The costs and benefits estimated in this chapter are based on average costs per acre from studies of damage by RIFAs in the southeastern United States. Actual costs .incurred by individual households and agricultural producers can vary substantially from these average costs. Because of its drier climate, costs in California may also deviate from the wetter, southeastern United States.

Costs to Urban Households Urban households incur costs to treat mounds, repair damage to electrical equipment, and for medical and veterinary expenses. In a survey of South Carolina households, the average total cost per household due to RIFAs was $80 (Dukes et al. 1999). Costs, however, were not the same across regions. In lower risk regions average costs were only $33, while in higher risk regions they were $104.

Given the wide range in costs and climatic conditions in California, three methods were used to estimate the economic effects of RIFA infestations on urban households. The first was to multiply the number of households in counties susceptible to RIFA infestations by the average cost per household for all households. The second method was to multiply the number of households in the low-risk counties by the average low-risk cost, and the number of households in the high-risk counties by the average high-risk cost, and then add the two together. The third method was to multiply the number of households in susceptible counties by the average costs per low-risk household.

In 1999 the total number of households in susceptible counties was 10,363,432 (Department of Finance 2000). In the low-risk counties there were 2,711,036 households, and in the high-risk counties 7,652,396. Total estimated cost of RIFAs to urban households would then be $829 million when average costs for all households are used to calculate total cost, $885 million when cost is calculated by region, and $342 million when the average low-risk cost is used for all susceptible households.

Costs to Agriculture

TREE CROPS AND VINEYARDS Tree crops and vineyards use hand labor throughout the year. Tasks requiring hand labor include pruning, raking, and harvesting. In fields infested, with RIFAs, crews may not be able to enter to complete these tasks because of the aggressive nature of the ant and the painful stings, or may request a higher fee to compensate for the additional health risks. Alternatively, producers could treat fields with insecticides and control RIFAs before crews enter. In our analysis we assume that producers would treat twice a year to control RIFAs with the growth regulator Extinguish, which is registered for use on all tree crops and vineyards in California. Total application costs for both treatments are $55 per acre.

The extent to which the RIFA would establish in groves, orchards, and vineyards may vary depending on previous treatments and agro-climatic conditions. Therefore, a range of acreage is used to estimate the additional costs to tree fruit, nut, and vine industries in California. A low-impact level of 10 percent of total acreage affected, a medium level of 25 percent, and a high level of 40 percent are used based on conversations with scientists familiar with RIFA problems in Florida and Arkansas (Thompson 2000).

Absolute increases in costs would range from $81,000 for figs at low-impact levels to $16.45 million for grapes at high levels (Table 10.1). Total increases in costs for all crops would range.from $12 million at low-infestation levels to $48 million at high levels. While the dollar amount is substantial, as a percentage of total farm receipts it is less than 1 percent, even when 40 percent of acreage is affected. Costs as a percentage of farm receipts are greatest for figs, walnuts, and prunes, and lowest for lemons, nectarines and peaches, pears, apples, and plums.

ADDITIONAL EFFECTS ON CITRUS The RIFAs may also damage young citrus when they build their nests around or near the base of trees one to four years old. The ants feed on the bark and cambium to obtain sap, often girdling and killing the young trees. They also chew off new growth at the tips of branches and feed on flowers of developing fruit. Dead trees must be removed and replanted, raising the costs to establish an orchard. Based on field experiments in Florida, nursery stock mortality in untreated groves increased three- to fivefold per hectare, and total loss of newly planted groves due to RIFA feeding occurred in a few instances (Banks et al. 1991, Knapp 2000).

To prevent tree mortality, growers may choose to treat groves with insecticides. Groves should be treated for two to three years until young trees develop woody bark that RIFAs cannot chew through (Knapp 2000). RIFA control undertaken during grove establishment would increase investment costs and must be depreciated over the life of the grove. Establishment costs increase to $110 per acre if the grove is only treated the first two years and to *$165* per acre for three years when groves are treated with two applications of Extinguish at an annual cost of *$55* per acre. Depreciation of the additional investment costs to establish the grove would increase annual cash costs by $9 per acre when treatments last two years, and by $13 per acre for three years. This increase in costs is less than *0.5* percent of the total annual cash costs based on University of California Cooperative Extensive farm budgets for citrus.

VEGETABLES AND MELONS Tite RIFA builds nests around the edges of fields planted in vegetable crops because frequent discing in the fields disrupts nests in the interior. From the edges they can enter fields and damage crops. Most damage is from consumption of developing fruit, seeds, roots, or tubers. Documented losses from RIFAs include a 50 percent yield loss on eggplants and a 2.4 to 4 percent plant loss on sunflowers (Adams 1983; Stewart and

Table 10.1 RIFA effects on selected tree and vine crops

			Additional costs to industry, Acreage affected			Percent of farm receipts Acreage affected	
Crop	Acres	Farm receipts	10%	25%0	40%	10%	25%0 40%
	(000)		($000s)			(%)	
Almonds	456	1,165,150	2,509	6,273	10,037	0.22	0.540.86
Apples	39	207,151	216	541	865	0.10	0.260.42
Apricots	21	57,309	114	286	457	0.20	0.500.80
Avocados	58	272,406	321	802	1,283	0.12	0.290.47
Cherries	18	79,103	96	241	386	0.12	0.300.49
Figs	15	18,149	81	203	325	0.45	1.121.79
Grapefruit	17	73,794	93	232	371	0.13	0.310.50
Grapes	747	3,178,940	4,111	10,277	16,444	0.13	0.320.52
Lemons	49	347,329	271	677	1,083	0.08	0.190.31
Nectarines & peaches	110	556,535	604	1,511	2,417	0.11	0.270.43
Olives	34	73,677	185	463	741	0.25	0.631.01
Oranges	205	906,317	1,125	2,813	4,500	0.12	0.310.50
Pears	19	90,479	105	264	422	0.12	0.290.47
Pistachios	65	181,678	358	895	1,431	0.20	0.490.79
Plums	43	199,801	238	595	952	0.12	0.300.48
Prunes	86	151,822	471	1,176	1,882	0.31	0.771.24
Walnuts	202	344,848	1,109	2,774	4,438	0.32	0.801.29
Total	2,183	7,904,486	12,009	30,022	48,035	0.15	0.380.61

aTreatment costs are $55 per acre.

Vinson 1991). In the sunflower field no further damage was observed after a treatment with insecticides. It is often the case though, that crop damage will not be significant enough to make it economically justifiable to treat (Lofgren 1986).

While losses from crop damage may not always be greater than the costs to treat the RIFA, many vegetable and melon crops are hand-harvested. Therefore, growers may need to treat fields for worker protection, even though direct damage by RIFAs may be minor. To control RIFAs in vegetable and melon fields two applications of Extinguish would be applied per year at a total cost of *$55* per acre. Because ant pressures will vary from year to year, a range of acreage is again used to determine the potential range in costs. Thus, industry costs were calculated for infestation levels of 10, *25,* and 40 percent.

Total potential costs to the vegetable and melon industries would range from $3.7 million when only 10 percent of acreage is infested to *$9.2* million when the infestation level is *25* percent, and to $14.8 million when the level is 40 percent (Table *10.2).*

While the dollar figures would be large, as a percentage of farm receipts they would be less than 1 percent in all cases, and under *0.5* percent in most, even when up to 40 percent of. acreage is affected.

ROW AND FIELD CROPS The large nest mounds of RIFAs interfere with cultivation and mowing. In mowing weeds or cutting alfalfa, farm operators must either raise the cutting bar to prevent damage, switch from sickle bar to disc type cutters, repair equipment damaged by the mounds, or use insecticides to destroy colonies (Thompson et al. *1995).*

Nonyield damages to row crops such as wheat, rice, and cotton include downtime to repair combines, electrical problems with pumps and machinery, other equipment damage, building damage, and medical expenses. In a survey of Arkansas row crop producers, nonyield costs of RIFAs per farm were $1,478. Over half of these costs were due to combine breakage and downtime for repairing cutter blades. Most damage to combines occurs from harvesting soybeans, a crop not grown in Cali-

Table 10.2 RIFA effects on selected vegetable and melon crops

			Additional costs to industry' Acreage affected			Percent of farm receipts Acreage affected		
Crop	Acres	Farm receipts	10%	25%	40%0	10%	25%	40%
	(000)	-__---_---($OOOs)-----_---			_----(%)----_			
Artichokes	10	68,405	55	138	220	0.08	0.20	0.32
Asparagus	31	109,624	171	428	685	0.16	0.39	0.63
Beans, fresh	5	25,758	25	63	101	0.10	0.25	0.39
Broccoli	120	467,088	660	1,650	2,640-	0.14	0.35	0.57
Brussels sprouts	3	21,715	18	44	70	0.08	0.20	0.32
Cabbage	14	74,401	76	191	306	0.10	0.26	0.41
Cantaloupe	63	240,525	345	861	1,378	0.14	0.36	0.57
Cauliflower	39	189,263	213	533	853	0.11	0.28	0.45
Celery	24	227,443	133	333	534	0.06	0.15	0.23
Cucumbers	6	52,676	35	87	139	0.07	0.16	0.26
Garlic	34	220,199	184	461	737	0.08	0.21	0.33
Honeydew	21	71,720	113	282	451	0.16	0.39	0.63
Lettuce, head	142	868,571	778	1,946	3,113	0.09	0.22	0.36
Lettuce, leaf	42	261,755	231	578	924	0.09	0.22	0.35
Lettuce, Romaine	27	156,520	149	371	594	0.09	0.24	0.38
Onions	39	169,254	214	534	855	0.13	0.32	0.50
Peppers, bell	22	162,707	118	296	473	0.07	0.18	0.29
Spinach, fresh	15	84,816	83	208	332	0.10	0.24	0.39
Watermelon	17	84,216	93	233	373	0.11	0.28	0.44
Total	672	3,556,651	3,694	9,236	14,777	0.10	0.26	0.42

aTreatment costs are $55 per acre.

fornia. The next highest cost was for repair of electrical equipment. When costs were calculated on a per acre basis, the costs for all yield and nonyield damage were $1 for rice, *$0.25* for wheat, and $1.35 for hay. In general, it was not cost effective to treat for RIFAs in field crops.

RIFAs are predators of many agricultural pests. Among the pests that are present in cotton grown in California, the tobacco budworm and pink and cotton bollworms would all be preyed upon by the RIFA. Field experiments in Texas show that the presence of RIFAs significantly decreases bollworms in cotton fields and increases yields (Brinkley *1991)*. However, because the RIFA also damages electrical machinery and clogs sprinklers and irrigation equipment, the net result on profits is ambiguous. Surveys from Arkansas show a net profit in some cases and net losses in others (Semevski *1995)*. Therefore, no losses or benefits are estimated for cotton.

The total number of susceptible farms in California, based on the *1997* Census of Agriculture, is *5,526 (U.S.* Department of Agriculture *2000)*. This includes grain, oilseeds, and hay enterprises. The cost per farm is set at the average level incurred per farm by Arkansas growers. As in the case of tree and vine crops, all field crops would not be affected. Costs are again calculated assuming 10, *25,* and 40 percent of acreage would be affected. Total estimated costs are *$817* thousand when 10 percent is infested, *$2.0* million when *25* percent is infested and $3.3 million when 40 percent is infested.

Hay growers may have additional costs due to quarantine regulations. Hay stored on the ground may not be moved out of a quarantined area. How this affects growers would depend on the amount of production that would leave the area and the cost of alternative storage methods. Even if hay is not transported out of the region, growers would need to take precautionary measures against RIFAs because horses, cattle and other livestock would not consume ant infested hay.

NURSERY INDUSTRY All nurseries within a quarantine area would need to meet quarantine regulations in order to ship plants outside of the quarantined region. Open land on which nursery stock is grown would need to be treated once every three months with either fenoxycarb or hydramethylnon, alternating between the two insecticides. In addition, growers would need to treat the individual containers in which the plants are grown. Acceptable treatments include either a drench with chlorpyrifc s, diazinon, or bifenthrin, *30* days before shipping, or incorporating a granular formulation of bifenthrin into the soil every six months. Because of environmental regulations concerning pesticide runoff and the need to treat frequently with chlorpyrifos, bifenthrin is more commonly used than chlorpyrifos.

Annual costs to treat nurseries for RIFAs would be about *$650* per acre. The applications of fenoxycarb and hydramethylnon are *$60* per acre, with the use of bifenthrin accounting for the remaining costs. According to the American Nursery and Landscape Association, the treatment cost per plant per container is 2¢. Only open nursery acreage that produces container plants would be affected by the quarantine regulations. Based on the *1997* Census of Agriculture, *28,000* acres were devoted to open-field nursery production of bedding and flower plants, foliage, potted flowers, and other nursery stock. Because nurseries within the quarantined regions must treat in order to ship outside of the quarantine, even if the nursery does not have RIFAs, almost all nurseries would be affected by the regulations. Total costs to the nursery industry are thus calculated on all openfield acreage and are equal to *$18.2* million. In addition, nurseries would need to be inspected for RIFAs by placing bait out quarterly and observing the presence or absence of RIFAs on the bait at a cost of *$38* per acre. Additional costs for inspection and certification are about $1.40 per acre.

Sod growers are also affected by quarantine regulations. Insecticide treatment for sod would be an application of chlorpyrifos. Materials and application costs are *$330* per acre. Based on the *1997* Census of Agriculture, a total of *13,665* acres would be affected. Total costs are equal to *$4.5* million.

Greenhouses that use containers placed on benches are exempt from the quarantine regulations. However, greenhouse operations would still need to treat if infested with RIFAs for worker safety and to protect electrical and irrigation equipment and machinery. These expenses would increase the costs to the nursery industry.

ANIMAL INDUSTRIES The RIFA stings cattle and other livestock, infests hay and other food sources, and damages electrical and irrigation equipment (Barr and Drees *1994).* The ants are attracted to mucous membranes located in the eyes and nostrils. Fire ant stings cause blindness and swelling and may end in suffocation. Immobilized animals, such as penned or newborn livestock are at the greatest risk. A survey of Texas veterinarians indicated that the most common livestock problem was skin inflammations from RIFA stings *(49.6* percent of all cases). The next most common problem was blindness *(20.1* percent) followed by secondary infections (14.4 percent) and injury to convalescent animals *(12.3* percent).

Over *50* percent of the cases seen by the veterinarians were to treat pets and small animals. While pets 'and small animals were treated more often, mortality associated with the RIFA was greatest for cattle. However, it was often difficult to determine if RIFAs caused cattle death or if the ants were observed on animals after death. As a percentage of all cases seen by veterinarians, cases involving RIFA-related problems account for less than 1 percent.

In avoiding ants, livestock may also become malnourished or dehydrated when the ants invade their food and water. Cattle would not consume hay, nor would poultry eat feed; infested with RIFAs. The agitation caused by RIFAs invading poultry houses can decrease egg production. Extra expenses would be incurred to purchase RIFA-free hay or to treat around the perimeter of buildings to prevent RIFA invasions of calving pens, dairy and hog barns, and poultry houses.

Since the RIFA preys on insects, it may provide a benefit to the cattle industry from predation on ticks and horn flies in their immature stages. Because ticks and flies are disease vectors, the RIFA may potentially decrease the incidence of animal diseases carried by them.

RANGELAND EFFECTS Losses to ranchers from the RIFA include damage to electrical equipment, hay-harvesting equipment, and cattle injury and loss. In a survey of Texas ranchers, *71* percent of respondents reported some type of economic loss (Teal et al. *1998).* The largest damage levels were estimated at *$28.06* per acre, but many counties in the drier, western regions had damages of less than *$2* per acre: Even though damages are estimated on a per acre basis, about *95* percent of the total costs occur on about *5* percent of the land.

Most costs would be from damages around buildings, electrical equipment, and water sources. Also, as in the case of households and cropland, costs would vary widely. Some ranchers would experience large infestations and, consequently, large costs while nearby ranchers may have little damage.

Because California's climate differs markedly from that of Texas, costs in California are more likely to resemble costs incurred by ranchers located in Texas's western counties than for all counties in Texas. Furthermore, a significant proportion of rangeland in California is in counties too cold or dry to support RIFAs. These rangelands are located in northern California, along the Sierra Nevada mountain range, and in southern California.

Excluding rangelands in counties not susceptible to RIFAs results in a potential *15,759* acres at risk (U.S. Department of Agriculture *2000;* FRRAP *1988).* This acreage includes private rangelands, Bureau of Land Management land, and land grazed in. National Forests. As in the case of agricultural crops, different impact levels are used to determine the potential range in costs. RIFAs will not be a problem on all susceptible acreage, however. Because a higher proportion of ranchers reported economic losses from the RIFA than were reported by growers, a higher range of acreage is used. Infestation levels of *25* percent, *40* percent, and *65* percent of all susceptible acres are used to determine the range in costs. Per acre costs are *$1.50.* Total annual potential costs are *$5.9* million for the low-impact level of *25* percent affected, *$9.5* million for *40* percent, and *$15.4* million for *65* percent.

OTHER EFFECTS Quarantine regulations would require that farm machinery and soil must be treated before leaving a quarantine area. Other agricultural activities, such as beekeeping, would also have to meet quarantine restrictions before being moved from one field or orchard to another.

Not included in our analysis are the costs to repair and replace irrigation equipment. Because the RIFA has previously established in areas with rain-fed agriculture, costs involving damage to irrigation equipment are not available.

Wildlife Many claims have been made that imported fire ants affect wildlife and reduce biodiversity (Allen et al. 1994). When imported fire ants move into an area, they often displace native organisms. Due to their enormous population size and foraging efficiency, they become formidable competitors and predators within their territory. Thus, biodiversity in many coastal and low-altitude wilderness areas of California may be at risk. Imported fire ants displace other ants and invertebrates and also inflict damage on ground-nesting birds and mammals. The displacement of native ants and other animals may also disrupt native plant communities. Native ants assist the propagation of native plants by spreading seeds. As the ants decline, native plant species may also decline in fragile areas, and in turn threaten the animals that feed on those plants.

The RIFA appears to primarily affect bird and reptilian populations by destroying the eggs and the young. One study in Texas found that RIFA predation caused a 92 percent reduction in the number of waterbird offspring when natural habitants were not treated for infestations. Of special significance to California are studies that have documented ant predation on tortoise and reptile hatchlings. Fire ants may also prey on quail, but biologists have yet to definitively answer this question. In addition, many past chemical control measures for fire ants adversely affected wildlife. The newer products, however, do not adversely affect wildlife.

Many endangered species are among the wildlife threatened (Table 10.3). Either directly as a source of food or indirectly from predation on a food source, 58 out of California's 79 endangered animal species are susceptible to RIFAs. Insects, young rodents, reptiles, amphibians, and ground-nesting birds are directly susceptible through RIFA feeding. In addition several endangered birds, such as the northern spotted owl and bald eagle, may be at risk through a reduction in food sources. While no exact value has been estimated for the increased risk of extinction of specific endangered species, most people value preservation of endangered species and their potential increased risk represents an additional cost of RIFA establishment.

Discussion of the Consequences of the Establishment of the R1FA The spread of RIFAs throughout California will result in the establishment of a major nuisance pest. The greatest costs will be from the repair of electrical and irrigation equipment, insecticide treatments to prevent harm to human and animal health, and treatments to meet quarantine restrictions. Annual aggregate losses are estimated to be between $387 million at the low-impact level and $989 million at the high (Table 10.4). Costs to households account for about 89 percent of the total estimated costs.

Other significant costs would accrue from the disruption of ecosystems, which in turn would threaten California's native plant and animal biodiversity. It is also possible that dozens of endangered species in California will face a greater risk of extinction.

Cost/Benefit Analysis

The cost/benefit analysis will compare the expected costs of eradication to the expected benefits of preventing establishment. The cost/benefit analysis takes into account uncertainty over the success of the eradication program and differences in the number of years during which the costs and benefits accrue. Eradication costs are incurred for one 5-year period, two 5-year periods and one 10-year program. Eradication benefits will continue into perpetuity.

Uncertainty is incorporated into the cost/benefit analysis by estimating an expected value. An expected value is equal to the probability of an event happening times the value of the event. For a one-period model, the expected costs are equal to the total discounted program costs because it is known with certainty that those costs will be incurred. The expected benefits are equal to the probability of success times the present value of the benefits of preventing establishment.

For the two 5-year programs it is uncertain if the costs will be incurred during the second period. The expected costs are equal to the actual discounted costs that will be incurred during the first period plus the expected additional costs.

Table 10.3 Endangered species susceptible to a RIFA invasion

Endangered species	Reason	Endangered species	Reason
Beetle, delta green ground	Yes-insect	Fairy shrimp, vernal pool	Yes-eggs in soil of dried pools
Butterfly, bay checkerspot	Yes-insect	Tadpole shrimp, vernal pool	Yes-eggs in soil of dried pools
Butterfly, El Segundo blue	Yes-insect	Lizard, blunt-nosed leopard	Yes-reptile
Butterfly, Lange's	Yes-insect	Lizard, Coachella Valley	Yes-reptile
metalmark Butterfly, lotis		fringe-toed Lizard, Island	
blue Butterfly, mission blue	Yes-insect	night Snake, giant garter	Yes-reptile
Butterfly, Myrtle's	Yes-insect	Snake, San Francisco garter	Yes-reptile
silverspot Butterfly,	Yes-insect		Yes-reptile
Oregon silverspot			
Butterfly, Palos Verdes	Yes-insect	Tortoise, desert	Yes-reptile
blue Butterfly, San Bruno			
elfin Butterfly, Smith's blue	Yes-insect	Turtle, green sea	Yes-reptile
Fly, Delhi Sands flower-			
loving Flycatcher,	Yes-insect	Turtle, leatherback sea	Yes-reptile
Southwestern willow	Yes-insect	Turtle, loggerhead sea	Yes-reptile
Gnatcatcher, coastal	Yes-insect	Turtle, olive (=Pacific)	Yes-reptile
California Moth, Kern		Ridley sea Snail, Morro	
primrose sphinx Beetle,	Yes-insect	shoulderband	Yes-mollusk
valley elderberry longhorn			
Goose, Aleutian Canada	Yes-insect	Kangaroo rat, Fresno	Yes-rodent young
Plover, western snowy			
Rail, California clapper	Yes-insect	Kangaroo rat, giant	Yes-rodent young
Rail, light-footed clapper			
Rail, Yuma clapper Shrike,	Yes-insect	Kangaroo rat, Morro Bay	Yes-rodent young
San Clemente loggerhead			
Tern, California least	Yes-ground-nesting bird	Kangaroo rat, Stephens'	Yes-rodent young
	Yes-ground-nesting bird	Kangaroo rat, Tiptop	Yes-rodent young
	Yes-ground-nesting bird	Mouse, Pacific pocket	Yes-rodent young
	Yes-ground-nesting bird	Mouse, salt marsh harvest	Yes-rodent young
	Yes-ground-nesting bird	Vole, Amargosa	Yes-rodent young
	Yes-ground-nesting bird	Mountain beaver, Point Arena	Yes-habitat disruption
	Yes-ground-nesting bird	Condor, California	Possible-reduction in food source Possible-reduction
Towhee, Inyo California	Yes-ground-nesting bird	Eagle, bald	in food source Possible-reduction in food
Pelican, brown	Yes-ground and tree nesting Yes-soft-shelled eggs	Falcon, American peregrine	source Possible-reduction in food source
Frog, California red-legged Salamander, desert slender		Owl, northern spotted	Possible-reduction in food source Possible-low
	Yes-soft-shelled eggs	Sparrow, San Clemente sage	tree-nesting bird Possible-low tree-nesting
Salamander, Santa Cruz long-toed	Yes-soft-shelled eggs	Murrelet, marbled	bird
Toad, arroyo southwestern	Yes-soft-shelled eggs	Vireo, least Bell's	

The additional costs are calculated as the probability that additional costs will be needed the second period, times the actual discounted costs for the second period.

Total expected costs = C, + (1-P,)*Cz

where subscripts denote the period, C is total discounted costs, and P is the probability of success for the first period.

The expected benefits are equal to the probability of receiving them during the first period times the benefit amount, plus the probability

Table 10.4 Total annual costs of RIFA establishment in California

Category	Impact Low	Medium	High
	($ million) -		
Tree and vine crops	12.0	30.0	48.0
Vegetable crops Field	3.7	9.2	14.8
crops Nursery Sod	0.8	2.0	3.3
Rangelands Total	18.	18.2	18.2
agricultural Total	2	4.5	4.5
household Total	4.5	9.5	15.4
	5.9	73.5	104.2
	45.1	829.0	885.0
	342.0	902.5	989.2

that they will not, times the probability that they will be received during the second period, times the benefit amount. With two unknown probabilities, the probability of success in period one is set at 0.1 percent, which reflects the qualitative assessment that success during the first 5 years is unlikely.

Expected benefents = P,*B+(1-P,)*PZ*B

where B is equal to the present value of total benefits.

The annual costs of establishment shown in Table 10.4 are the estimated losses once the RIFA has spread completely throughout its susceptible range in California. We assume that this level would be achieved in 10 years if all public control activities cease based on infestation rates in the southeastern United States. The costs for years 1-10 depend on the rate of spread of the pest. For an exotic species such as the RIFA, the rate of spread will be relatively slow at first. It increases exponentially as the size of the infestation increases and then tapers off as the ant spreads into the last few susceptible areas.

For this analysis the rate of spread is expressed as a percentage, or share, of the total susceptible area and is given by the expression

Share(t) = *Share(max)*

where

- *I Share(t,)* ~_P* ( )
a - In *Share(max)-Share(tj)* *Share t*

and

b=!n *5*Share(max)* *In* *Share(t,)*
*((Share[max)-.5*Share[mas])) (Share(max)-Share(t,) ,*

$t_{50\%}-t_1$

Share(max) is equal to 100 percent and represents the share of total annual costs incurred once the RIFA is fully established. Share(t) is the share incurred at time t while the ant is spreading and becoming established. $T_{50\%}$ is the time period when the ant has spread 50 percent.

To estimate the rate of spread, two pieces of information are needed: the initial share at ti and the time period at which the ant has achieved a share of 50 percent. We assume that the initial share is 1 percent and that the RIFA has spread throughout 50 percent of its range by year 6. The present value of the benefits is calculated as the sum of the discounted annual cost of establishment multiplied by the share infested from year 1 to year 10, plus the sum of the discounted values of the total annual costs from year 11 into perpetuity.

Ifthe probabilities were known, then the expected costs and benefits can be calculated directly and compared. For the RIFA eradication program, these probabilities are not known. From the expected cost and benefits equations, however, the probability at which the expected benefits equal at least the expected costs may be calculated and then compared to a qualitative assessment to determine feasibility. The qualitative assessment may rank the probability of success anywhere from very high to very low. As the value of the breakeven probability increases, the likelihood that it will be greater than the qualitative assessment .decreases.

Discussion of Cost/Benefit Results

The three cost scenarios included in the analysis and breakeven probabilities are calculated for the one-period program of 5 years, the oneperiod program of 10 years, and the two 5-year periods at the low-, medium-, and high-benefit level.

As shown in the table, the higher the costs of establishment, the lower the probability needed for the breakeven value to be reached. In all cases the breakeven probability of success is relatively low. When the length of the eradication program increases from 5 to 10 years, eradication costs increase, causing the breakeven probability of success to also increase. The ab-

Table 10.5. Costlbenefit analysis

Benefits		Breakeven probability		
		One	Two	One
		5-year	5-year	10-year
Level	Amount	period	periods•	period
	($ billion)	------------(%)----------		
Low	3.8	1.04	1.72	1.73
Medium	8.8	0.45	0.73	0.74
High	[illegible]	0.41	0.67	0.68

aWhen the probability of success in year 1 is 0.1%.

solute increase in percentage points is relatively small, however. Between the 5-year program and the 10-year program, the increase in percentage points is only 0.26 for the high economic impact level to 0.68 for the low-impact level. While low, this represents an approximate increase of 64 percent over the 5-year program.

When the eradication program increases from one 5-year period to two 5-year periods, the probability of success again must increase. However, the probabilities increase by slightly less than one 10-year program. At the highimpact level, the probability of success increases to 1.73 percent for the 10-year program, but only to 1.72 percent for .the two 5-year programs. Even though the probability of success is 0.1 percent for the first 5 years of the two 5year programs, having a nonzero probability of success lowers the probability of success needed for the expected benefits of an additional 5year program when compared with the 10-year program.

While the estimated probabilities are very low, it is possible. that they may not be low enough. At the start of the public eradication program expert opinion was solicited, and a consensus emerged that a nonzero probability existed that the RIFA could be eradicated given the size of the infestation at that time and the amount of resources available. Since the start of the eradication program new discrete infestations have been identified; however, no increase in resources has been provided to increase the scope of the eradication program. Consequently, updating qualitative assessments of the biological feasibility of eradicating the RIFA is important.
.

Conclusion

Ideally, regulatory agencies and academic institutions

otic pest problems. This approach has worked well in Texas, and the fire ant program there should serve as a model for California. The Texas Agricultural Experiment Station and Extension Service, Texas Department of Agriculture, Texas Park and Wildlife Department, Texas Technological University, and the University of Texas are all collaborating in a coordinated effort to address their fire ant problem through research, education, and regulatory programs. Basic and applied research is designed to improve methods of control. Community-based education provides training on control. Regulatory programs through surveys determine distribution ,and abundance of fire ants and provide effective quarantine programs to prevent their spread.

In California, a close collaboration between CDFA and the University of California would bring together two complementary organizations, each bringing their own strengths and talents to bear on the current fire ant crisis. CDFA, as a regulatory agency, is in charge of survey and detection, as well as quarantine. The University of California with its Experiment Station and Extension Service is ideally suited for research and education. The University of California's Exotic Pest Center is a consortium of University of California scientists who are experts on a variety of pests. The Exotic Pest Center is uniquely qualified to offer its expertise to help find solutions to urgent problems such as the one California is now facing with fire ants. In order to succeed, these two organizations must be dedicated to working together quickly and efficiently, before fire ants become. permanently entrenched in California.

References

Adams, C.T. 1983. "Destruction of Eggplants in Marion County, Florida by Red Imported Fire

Ants (Hymenoptera: Formicidae)." *Florida Entomologist.* 66:518-520.

Allen, C.R., S. Demarais, and R.S. Lutz. 1994. "Red Imported Fire Ant Impact on Wildlife: An Overview." *Texas Journal of Science.* 46:51-59.

Banks, W .A., C.T. Adams, and C.S. Lofgren. 1991. "Damage to Young Citrus Trees by the Red Im ported Fire Ant (Hymenoptera: Formicidae)." *Journal of Economic Entomology.* 84:241-246.

Barr, C.L., and B.M. Drees. 1994. "Results from the Texas Veterinarian Survey: Impact of Red Imported Fire Ants on Animal Health." In *Proceedings of the 1994 Imported Fire Ant Conference,* Mobile, AL, May 9-11.

Brinkley, C.K., R.T. Ervin, and W .L. Sterling. 1991. "Potential Beneficial Impact of Red Imported Fire Ant to Texas Cotton Production." *Biological Agri culture and Horticulture.* 8:145-152.

Department of Finance, State of California. 2000. City/County Population and Housing Estimates, 1991-2000 with 1990 Census Counts. Sacramento, California. http://www.dof.ca.gov/htmI/ Demograp/E-5.xls.

Dowell, R.V, A. Gilbert, and J. Sorensen. 1997. "Red Imported Fire Ant Found in California." *California Plant Pest & Disease Report.* 16:50-55.

Dukes, ftR., S.E. Miller, M.S. Henry, B.J. Vandermey, and PM. Horton. 1999. "Household Experiences with the Red Imported Fire Ant in South Carolina." Research Report. Department of Agricultural and Applied Economics. Clemson University. 17 pp.

Forest and Rangeland Resources Assessment Program (FRRAP). 1988. "California's Forests and Rangelands: Growing Conflict Over Changing Uses-An Assessment." California Department of Forestry and Fire Protection. Sacramento, California. 348 pp.

Greenberg, L., J. Kabashima, J. Klotz, and C. Wilen. 1999. "The Red Imported Fire Ant in California." *Pacific Coast Nurseryman.* 58:8.69-73.

Greenberg, L., J. Klotz, and J. Kabashima. 2001. "Red Imported Fire Ant." *Pest Notes,* publication 7487. UC ANR publication. Davis, California. 3 pp-

Killion, M.J.,. and W .E. Grant. 1995. "A Colony Growth Model for the Imported Fire Ant: Potential Geographic Range of an Invading Species." Eco *logical Models.* 77:73-84.

Klotz, J.H., J.R. Mangold, K.M. Vail, L.R. Davis, Jr., and R.S. Patterson. 1995. ' A Survey of the Urban Pest Ants (Hymenoptera: Formicidae) of Peninsular Florida." *Florida Entomologist.* 78:109-118.

Knapp, Joseph. Professor of Entomology. University of Florida. November 2000. Personal communication.

Knight, R.L., and M.K. Rust. 1990. "The Urban Ants of California with Distribution Notes of Imported Species." *Southwestern Entomologist.* 15:167-178.

Lennartz, F.E. 1973. "Modes of Dispersal of *Solenopsis invicta* from Brazil into the Continental United States-A Study in Spatial Diffusion." MS Thesis, University of Florida, Gainesville. 242 pp.

Lewis, V R., L.D. Merrill, TH. Atkinson, and J.S. Wasbauer. 1992. "Imported Fire Ants: Potential Risk to California." *California Agriculture* 46:29-31.

Lofgren, C.S. 1986. "The Economic Importance and Control of Imported Fire Ants in the United States." In S.B. Vinson, Ed., *Economic Impact and Control of Social Insects.* New York: Praeger Publishers. pp. 227-256.

Lofgren, C.S., W .A. Banks, and B.M. Glancey. 1975. "Biology and Control of Imported Fire Ants." *An nual Review of Entomology.* 20:1-30.

McDaniel, S.G., and WL. Sterling. 1979. "Predator Determination and Efficiency on *Heliothis virescens* Eggs in Cotton Using 3zP" *Environmental Entomology.* 8:1083-1087.

McDaniel, S.G., and W .L. Sterling. 1982. "Predation of *Heliothis virescens (F.)* Eggs on Cotton in East Texas." *Environmental Entomology.* 11:60-66.

Olsen, Chris. 2002. Aventis Environmental Science. Personal communication to J. Klotz, May 15, 2002.

Porter, S.D. and D.A. Savignano. 1990. "Invasion of Polygyne Fire Ants Decimates Native Ants and Disrupts Arthropod Community." *Ecology.* 71:2095-2106.

Reagan, TE. 1981. "Sugarcane Borer Pest Management..ln Louisiana: Leading to a More Permanent System." In *Proceedings of the 2nd InterAmerican Sugarcane Seminar: Insect and Rodent Pests, 1981.* Florida International University, Miami, FL, Oct. pp. 100-110.

Semevski, R, L. Thompson, and S. Semenov. 1996. "Economic Impact of Imported Fire Ants and Selected Crops: A Synthesis from the Literature." In *'Proceedings of the 1996 Imported Fire Ant Research Conference.* New Orleans, LA, April 1618. pp. 93-80.

Slowik, TJ., H.G. Thorvilson, and B.L. Green. 1996. "Red Imported Fire Ant (Hymenoptera: Formicidae) Response to Current and Conductive Material of Active Electrical Equipment." Journal of Economic Entomology. 89:347-352.

Sterling, W.L. 1978. "Fortuitous Biological Suppression of the Boll Weevil by the Red Imported Fire Ant." Environmental Entomology. 7:564-568.

Stewart, J.S., and S.B. Vinson. 1991. "Red Imported Fire Ant Damage to Commercial Cucumber and Sunflower Plants." Southwestern Entomologist. 16:168-170.

Taber, S.W. 2000. Fire Ants. College Station, TX: Texas A&M University Press. 308 pp.

Teal, S., S. Segarra, and K. Moates. 1998. "Spatial Economic Impacts of the Red Imported Fire Ant on the Texas Cattle Industry:' Technical Research Report No. T 1-484. Department of Agricultural and Natural Resources, Texas Tech University. 38 pps.

Thompson, L.C., D.B. Jones, AN. Semevski, -and S.M. Semenov. 1995. "Fire Ant Economic Impact: Extending Arkansas' Survey Results over the South." In Proceedings of the Fifth International Pest Ant Symposia and the 1995 Annual Imported Fire Ant Conference, San Antonio, TX, May 2-4.

Thompson, Lynne. 2000. Professor, School of Forest Resources, University of Arkansas. Personal communication.

U.S. Department of Agriculture. 2000. 1997 *Census of Agriculture,* Vol. 1. Geographic Area Series. Part 5, California. AC97-A-5. Washington, D.C.: U.S. Dept. of Agriculture.

Vargo, E.L., and S.D. Porter. 1989. "Colony Reproduction by Budding in the Polygyne Form of *Solenopsis invicta* (Hymenoptera: Formicidae)." *Annals of the Entomological Society of America.* 82:307-313.

Vinson, S.B. 1997. "Invasion of the Red Imported Fire Ant: Spread, Biology, and Impact." *American Entomologist.* 43:23-39.

Vinson, S.B., and L. Greenberg. 1986. "The Biology, Physiology, and Ecology of Imported Fire Ants." In S.B. Vinson, Ed., *Economic Impact and Control of Social Insects.* New York: Praeger Publishers. pp. 193-226.

Williams, D.F 1986. "Chemical Baits: Specificity and Effects on Other Ant Species." In C.S. Lofgren and R.K. Vander Meer, Eds., *Fire Ants and Leaf-cutting Ants: Biology and Management.* Boulder, Colorado.: Westview Press. pp. 378-386.

Williams, D.F 1994. "Control of the Introduced Pest *Solenopsis invicta* in the United States." In D.F Williams Ed., *Exotic Ants: Biology, Impact, and Control Of Introduced Species.* Boulder, CO: Westview Press. pp. 282-292.

Wojcik, D.P., C.R. Allen, R.J. Brenner, E.A. Forys, D.P. Jouvenaz, and R.S. Lutz. 2001. "Red Imported Fire Ants: Impact On Biodiversity." *American Entomologist.* 47:16-23.