

SOLENOPSIS INVICTA



Other Latin names: *Solenopsis saevissima richteri* Forel (Buren 1972)

Common Name: Red imported fire ant

Description: *S. invicta* workers are small, light reddish brown to strongly dark brown ants (Buren 1972, in Lofgren et al 1975). They are polymorphic, and range from about 3mm-6mm in length. All workers have the same body proportions. Head width never exceeds abdomen width (Gilbert 1998), and head width varies from 0.5mm in minor workers to 1.5mm in major workers. The antenna are 10 segmented with a two segmented club (URL a). Pedicel is two segmented, propodeum is unarmed, and sting is present (URLa). Fire ants are often identified by their nest mounds, where brood is reared. Mounds are usually built in open sunny areas, and depending on soil type can reach up to one meter wide at the base, and one meter high (Lofgren et al. 1975). Their common name, fire ant, is derived from the fact that their sting causes a severe burning sensation. Their Latin name (*invicta*) appropriately means "invincible".

Native to where: *S. invicta* is believed to be a native of the seasonally flooded Pantanal region of southern Brazil (Buren et al. 1974, Ross and Trager 1990; in Tschinkel 1993). Its southern latitude limit is roughly 32'S (Tschinkel 1993).

Native Climate: The Brazilian homeland , the Pantanal, is a seasonally flooded headwater. Details of climate in this area are not known.

Biology and Ecology:

S. invicta workers are aggressive, mobilize quickly, and sting relentlessly when their mound is disturbed (Gilbert 1998). They are aggressive and effective at foraging and recruitment (Vinson 1994). They use their sting against colony intruders, and to subdue prey. These attributes make them very effective at resource defense, and hence highly competitive (Vinson 1994). They are omnivorous and opportunistic feeders (Vinson 1994). Though they prefer insects and arthropods (Tschinkel 1982, Morrill 1978; in Davidson and Stone 1989), they predate invertebrates, vertebrates, and plants (Vinson 1994), scavenge, and tend honeydew secreting invertebrates (Green 1952, in Davidson and Stone 1989).

S. invicta typically nest in the ground, in open sunny areas, but also in and around human constructs. Colonies consist of a mound, where brood is reared, and a series of underground foraging tunnels radiating from the mound. The tunnel system is extensive and allows workers to forage far from the mound at a wide range of soil surface temperatures, even those potentially lethal to workers (Porter and

Tschinkel 1987). According to Markin et al (1975) foragers need to travel less than 0.5m above ground to get to any point in their foraging territory.

Critical thermal limits (temperatures at which the locomotor ability of the ant was so reduced it could no longer escape lethal temperatures) were determined for *S.invicta* minor workers taken from different colonies (Cokendolpher and Phillips 1990). The mean minimum limit was 3.6°C, and the maximum 40.7°C. Critical thermal limits were determined to be influenced by thermal history (the temperature at which the ants were kept prior to testing) and the colony from which the ant came. The influence of thermal history on critical thermal limits suggests that *S.invicta* has an ability to deal with lower temperatures as winter approaches, which is beneficial for this ant since it is active year round (Cokendolpher and Phillips 1990).

S.invicta workers begin to forage at soil surface temperatures above 10°C, but do not continuously forage until air and soil temperatures reach 19°C (Markin et. Al. 1974). According to Porter and Tschinkel (1987) *S. invicta* forage over a soil surface temperature range of 12-51°C. However, they found that the single best predictor of foraging rates is soil temperature at 2cm depth. This is likely due to the extensive use by these ants of underground foraging tunnels. They found workers foraged when soil temperature (at 2cm) was between 15 and 43°C, and that maximal foraging rates occurred between 22 and 36°C. They also found that lower temperatures limit foraging activity much more often than higher temperatures.

Threshold levels of various activities were found by Markin et al (1974) to be temperature dependent in all parts of the ants range in the continental U.S. Brood production in spring began when the weekly mean soil temperature (at 5cm depth) rose above 10°C, worker and sexual pupae appeared at 20°C, and alates at 22.5°C. A mean soil temperature of 24°C was required for successful colony founding by new queens. Based on this data, the period of colony founding during a year was determined to range from 83 days (in northern Mississippi) to 198 days (in Florida). Rhoades and Davis (1967) found that optimal temperature ranges for *S.invicta* activity in Florida were: 75-85°F for air; 75-95°F for soil surface; and 65-80°F for soil at 4 inches depth. They also noted that activity was low when the soil was "very wet or very dry", and that a rain following a dry period always triggered a 2 or 3 day period of furious mound building activity, and increased foraging activity. In addition, they observed that no mating flight occurred on a day when the morning low soil temperature from the surface to the 4" depth was below 65°F, and that all mating flights noted occurred when the ambient air temperature was between 75 and 90°F. Relative humidity readings at the study site were all 80% or higher at the time of day when mating flights were actually observed. Flights were observed in mornings and afternoons, but no winged males or females were ever caught in the light traps at the study site during nights. Wind appeared to influence colonization patterns, as 89% of newly established colonies were leeward of the infested area under observation.

S.invicta colonies are extremely productive and grow rapidly. Queens can reproduce for five to seven years (Tschinkel 1987, in Tschinkel 1993), and can lay up to 5000 eggs/day (Tshinkel 1993). Workers are sterile. Colonies produce an estimated 4500 new queens/year that can disperse to new areas (Maxwell 1982, in Davidson and Stone 1989). Lab reared newly mated queens have been reported to produce 500,000 workers in their first year of life (Tschinkel and Porter 1988, in Tschinkel 1993). Mature colonies are amongst the largest of ant colonies, and often contain about 200,000 workers (Tschinkel 1993). New colonies can establish within 2 or 3 weeks of mating flights, and the average

length of time between colony establishment by a newly mated queen, and production of winged productive forms is between 15 and 18 weeks (Rhoades and Davis 1967).

Colonies occur in two forms: monogynous (“single queen”) and polygynous (“many queens”). The monogynous form is the more common form. Monogynous colonies have one reproducing queen, and are founded by mated queens that disperse via flight. This mode of dispersal allows mated queens to disperse up to a kilometer or more (Lofgren et al 1975) before landing to establish a new colony. Because they are territorial, monogynous colonies occur in lower densities than the polygynous form, with mound densities of up to 200/ha (Vinson 1994). Polygynous colonies have more than one, to hundreds, of reproducing queens. They are founded by one or several queens that usually travel on foot to a new location. This mode of dispersal results in a slower rate of invasion into new areas. Polygynous colonies, on the other hand, are not territorial and thus occur in densities up to six times that of the monogynous forms, with over 1000 mounds/ha. (Vinson 1994). Both types of colonies are also able to disperse on flowing water, and thus have an advantage in areas of seasonal flooding. When waters rise, they float as a mat of ants, surviving for weeks until the waters recede or they drift ashore. In the U.S., seasonal flooding eliminates most other ant species (Morrill 1974, in Tschinkel 1993).

Recent ecological studies have revealed that introduced *S.invicta* attain colony sizes and densities far in excess of those that occur in their native range (Porter et al. 1992, in Ross et al. 1996). This is presumably due, in part, to ecological release from the effects of natural enemies (predators and parasites) that normally limit survival and growth of established nests (Ross et al. 1996). It is argued that a population of native ants is one of the few factors that can slow the invasion of *S.invicta*. Newly mated *S.invicta* queens are susceptible to being killed by native ants before they can burrow into the ground. (Klein and Thompson b)

Value to humans:

In some cases, predation by *S.invicta* has played an important role in reducing pest insects in agriculture systems (Lofgren et al.1975). They are most beneficial in cotton, where they prey on boll weevil and *Heliothis* species (Sterling 1978, in Davidson and Stone 1989), and sugarcane where they prey on the sugarcane borer *Diatraea saccharalis* (Reagan et al 1972, in Lofgren et al. 1975).. *S.invicta* are also known to reduce hornflies and lone star ticks (pests of cattle) (Tschinkel 1993), and several species of pest diptera (Vinson 1994).

Attempted control strategies:

1. Quarantine of infested areas.
2. Broad scale treatments using baits with slow acting toxicants (Amdro, Affirm), with subsequent topical treatment of persistent mounds (with mound drench, dust, granule or bait insecticides)
3. Broad scale treatments using baits with insect growth regulators (Logic).
4. Biocontrol using phorid flies (research in progress)

Details of control strategies:

Eradication of *S.invicta* is not currently feasible in areas where the ant is established (Davidson and Stone 1989). Control strategies focus on reducing ant numbers and spread.

The USDA quarantine has reduced the rate of *S.invicta* spread via nursery stock, but nursery stock and other human modes continue to be important means of range expansion for this species (Tschinkel 1993).

The USDA fire ant quarantine was initiated in 1958 and is still in effect. This restricts the movement of queens and colonies in nursery stock and other human avenues of transport in an effort to control the spread of this species. Specifically it restricts the movement of soils, sod, hay, potted plants, plants with soil attached, and used soil-moving equipment from infested to uninfested areas (Klein and Thompson a).

Currently, chemicals are the most widely used and most effective method available for controlling *S.invicta* numbers (Williams 1994). The extremely high fecundity and rapid maturity of this ant make it necessary for control measures to be highly lethal (Davidson and Stone 1989). Contact treatments using a variety of commercially available chemicals are used primarily by homeowners to treat a few individual mounds (Banks 1994). If individual treatments are not 100% effective, colonies will simply relocate nearby (Green 1952 in Davidson and Stone 1989, Banks 1994). Slow acting toxic baits are much more effective at long term control. Those commercially available and effective in *S.invicta* control include Amdro with the active ingredient hydramethylnon, and Affirm, with the active ingredient abamectin (Banks 1994). Insect growth regulators (IGR's) are also effective at controlling this species. *S.invicta* colonies that ingest IGR's die much more slowly than those that ingest conventional bait toxicants, and users often object to the slow worker kill (Banks 1994). Regardless, the IGR bait Logic, with the IGR fenoxycarb, is available for *S.invicta* control (Banks 1994). Texas A&M University, Department of Entomology suggests using a two-step method for controlling *S.invicta* (URL e). It includes an initial broadcast of slow acting toxic bait, with subsequent topical treatments of persistent "problem mounds" with mound drench, dust, granule or bait insecticides.

According to Tschinkel (1993) the only long term hope of reducing *S.invicta* dominance where it occurs is through biocontrol. This is primarily because chemical control is not specific to *S.invicta*, and *S.invicta* is such an effective recolonizer. In other words, chemical controls may also eliminate invertebrate populations that keep *S.invicta* populations suppressed, allowing *S.invicta* to recolonize (as it quickly and effectively does) without any obstacles to colony establishment or growth. Tschinkel adds that any biocontrol strategy will probably require release of multiple agents to achieve substantial reduction of *S.invicta* populations, and that no biocontrol has ever been attempted against a social insect. A number of biocontrol agents are currently under investigation. One currently being tested in field trials are Brazilian flies in the genus *Pseudacteon* (family *Phoridae*), which are specialized *Solenopsis* parasitoids. Research has identified these flies as being species-specific agents that appear to keep *S.invicta* host populations in check and below pest status (Gilbert 1999). Field tests were conducted in Florida in 1997 (URL g), and field research is pending in Texas (Gilbert 1999).

Problems caused by this species outside Hawaii:

S.invicta is a pest species for several reasons. Problems associated with it are often due to its aggressiveness, and its ability to repeatedly sting. It primarily effects quality of life where it occurs, but also impacts agriculture, livestock operations, wildlife and natural ecosystems, damages electrical equipment, and incurs medical, and pest control costs.

S. invicta stings are painful and potentially dangerous. When the nest of this ant is disturbed the ants swarm over any nearby object, delivering multiple painful stings to the intruder (Davidson and Stone 1989). An unaware individual can easily sustain dozens of stings in a single encounter (Tschinkel 1993). Multiple stings by a single ant are common. The sting causes localized burning and itching followed by redness and formation of a pustule that, if broken, can become infected (Davidson and Stone 1989). The majority of people suffer only discomfort from the stings. However, a small fraction are hyper-allergic, and their response may range from swelling, to anaphylactic shock and death (Tschinkel 1993).

Because this ant occurs in high densities, it can severely alter human activities in infested areas. Brown (1982, in Davidson and Stone 1989) estimated that 2.5 million people were stung monthly. Victims may develop entomophobic reactions, that ultimately curtail normal outdoor activities (Davidson and Stone 1989). According to Texas A&M University (URL e), hunting, ranching and recreational activities have been greatly affected by the presence of this ant. They report that in some areas, it is impossible to sit in the grass or stand on a shoreline to fish without being stung. This situation not only discourages tourism and outdoor recreational activities, but also poses liability concerns to owners and managers of public areas, and reduces property values (URL f, Lofgren et al. 1975).

S. invicta has been reported in virtually every crop grown within the infested states (Davidson and Stone 1989). As this species is opportunistic, and feeds on both pest and beneficial insects, the extent of impact on crops is difficult to determine. However, Vinson (1994) suggests they can be a serious problem of cultivated crops. They are considered serious seed predators (Drees et al 1991 in Vinson 1994), attack and tunnel through roots and tubers of potatoes, sunflowers, and cucumbers (Boock and Lordello 1952, Adams et al. 1983, 1988, Stewart and Vinson 1991; in Vinson 1994), feed on plants and fruit of soybeans, okra and eggplants (Lofgren et al. 1975), and girdle young citrus trees (Brown 1982 in Vinson 1994). They have also been reported to feed on germinating seeds and seedlings of corn and sorghum during spring and occasionally cause loss of stand (Klein and Thompson a). In pecan orchards they've been shown to promote the pest status of *Dysmicoccus morrisoni*, a honeydew secreting pest (Tedders et al. 1990, in Vinson 1994).

Aside from potential agricultural damage caused by their foraging habits, *S. invicta* can also: damage irrigation systems (Klein and Thompson a); and, according to Davidson and Stone (1989), cause crop loss due to inefficient harvesting when combines must lift cutting bars over mounds; seriously affect cutting and mowing operations of hay, pastures and soybeans, causing damage to farm machinery and incurring equipment repair/replacement costs; reduce efficiency of farm workers due to worker avoidance of ants; increase worker time off and expenses for medical treatment; and make certain farm activities, such as removal of infested hay bales or on-the-spot repairs of machinery impossible if ants are present. Livestock are also affected. *S. invicta* sting and occasionally kill calves, small pigs, and other domestic animals (URL e, Lofgren et al. 1975).

S. invicta has serious impacts on wildlife. It has been reported to attack the eggs or nestlings of several species, including turtles and lizards (Vinson 1994), Wood Duck (Ridlehuber 1982, in Vinson 1994), colonial waterbirds (Drees 1994), Crested Caracara (Dickenson 1995), and endangered Least Tern (Lockley 1995). It is associated with a decline in nesting success of cliff swallows (Sikes and Arnold 1986, in Vinson 1994) and populations of northern bobwhite quail (Allen et al. 1995, in Pimental et al. 1999). It is believed to have caused deaths in several species of rodents (Gust, 1983, Masser and Grant, 1986, Flickinger 1989, in Killion et al. 1995); and is reported to negatively effect small

mammal densities (Smith et al 1990, Stoker 1992, and Killion and Grant 1993, in Killion et al 1995). *S.invicta* negatively affects invertebrate communities as well. In areas it invades it decimates the native ant fauna, and replaces even such tramp species as *Linepithema humile* (see Vinson 1994, Porter and Savignano 1990). Porter and Savignano (1990) showed a significant reduction of the abundance of isopods, erythraeid mites, and tumblebug scarabs at *S.invicta* infested sites, with a total arthropod species richness of 40% less than at sites without *S.invicta*. Vinson (1991, in Killion et al. 1995) attributed the presence of *S.invicta* to a significant decrease in a decomposer community. The polygynous form of *S.invicta* is reported to be especially devastating to fauna, due to its occurrence in high densities. As the polygynous form invades, the diversity and abundance of native arthropods and even vertebrates plummet (Tschinkel 1993). The food material that sustains these high ant densities is unknown, but the prospect of the displacement of native species is a serious concern (Porter et al. 1988, in Tschinkel 1993).

S.invicta has the potential to seriously impact plant assemblages in natural ecosystems, though changes in these have not been documented or evaluated (Vinson 1994). This ant's habit of moving and preying on seeds (Vinson 1972, Drees et al. 1991, in Vinson 1994) alters the ratios of the various seeds and the distribution of seeds available to develop, which can cause major changes in an ecosystem (Vinson 1994). Disturbing the assemblage of invertebrates and vertebrates in an area, may also ultimately affect plant assemblages as well.

S.invicta is a pest to property. It infests and damages structures and electrical equipment including air conditioners, traffic boxes, and airport runway lights, causing an estimated \$11.2 million in damages annually (URL e, Lofgren et al. 1975). In infested areas, it also results in contamination of water systems due to extensive pesticide use and misuse (URL f). It is difficult to estimate the cost of damage resulting from infestations of *S.invicta*. However, the estimated damage to livestock, wildlife, and public health caused by *S.invicta* in Texas is estimated to be \$300 million/yr. An additional \$200 million is invested in control per year (Vinson 1992, Pimental et al. 1999). Assuming equal damages in other infested states, damage totals about \$1 billion per year in the south (Pimental et al. 1999). An estimated \$7.9 million is spent annually by urban homeowners just on medical treatments due to fire ant stings (URL e).

Problems caused by this species within Hawaii:

S.invicta does not currently occur in Hawaii. However, the likelihood of its eventual introduction to the state is high. Current quarantine and inspection procedures are not effective barriers to alien ant introductions, as has been proved by the recent discovery of the pest ant *Wasmannia sp.* on the Island of Hawaii, which represents a new ant introduction to the state. Despite USDA quarantine efforts, spread via nursery stock and other human modes continue to be important means of range expansion for *S.invicta* (Tschinkel 1993). The establishment of *S.invicta* in California in 1998 dramatically increases the likelihood of an *S.invicta* introduction to Hawaii. California is a source of many imports to Hawaii, including nursery stock.

Should this species arrive in Hawaii, it has a high probability of becoming permanently established. This is because: queens fly, and disperse via mating flights, rendering control of spread impossible; most of the State offers habitat well within the thermal limits of the species; there are extensive areas of disturbed habitats such as pastures and agricultural land; and, Hawaii lacks the only factor thought to slow *S.invicta* invasions (i.e. native ants). It is possible that currently established alien ants might

slow the spread of *S.invicta* in Hawaii, should it reach the state. However, *S.invicta* is known to have displaced other pest ant species, including the Argentine ant (*L.humile*), in areas it has invaded.

Should *S.invicta* become established in Hawaii, the state could expect to encounter the same problems this species has caused elsewhere. Including impacts to wildlife populations, medical costs, costs of control, reduced property values, and reduced quality of life. The latter would seem exceptionally significant given Hawaii's dependence on the tourist industry.

History in the U.S.:

S.invicta has colonized over 275 million acres of the United States since its introduction about 60 years ago (URL c). Currently it is not feasible to eradicate in areas where it is established (Davidson and Stone 1989).

S.invicta was first introduced to the U.S. through the port at Mobile, Alabama between 1933 and 1945 (Lennartz 1973, in Lofgren et al. 1975). It dispersed extremely quickly, partially via mating flights, but mostly via transport by man of infested nursery stock (Lofgren et al. 1975, Tschinkel 1993, Davidson and Stone 1989). According to Tschinkel (1993) by the mid 1950's, its range consisted of a contiguous zone around Mobile and numerous incipient populations centered on nurseries throughout the southeast. While USDA quarantine procedures, initiated in 1958, reduced the rate of spread by nursery stock, this and other human modes continue to be important means of range extension for *S.invicta* (Tschinkel 1993). Much of the range expansion in the U.S. since the mid 1950's has consisted of filling in the space between incipient populations established during the first decade or two of the invasion (Tschinkel 1993). By 1962 *S.invicta* infested 126 million acres in 10 states (Davidson and Stone 1989). Currently, it infests over 275 million acres in 11 states (Alabama, Florida, Louisiana, Arkansas, Georgia, Mississippi, Oklahoma, North Carolina, South Carolina, Tennessee, and Texas) and Puerto Rico, with an average density of 1500-3000 ants/square meter (URL q). Isolated colonies have been found in New Mexico, Arizona, and Virginia (Williams 1994), and as far north as Delaware (URL g), and Maryland, which has battled at least eight infestations in the past decade (URL d). During 1998, *S.invicta* was discovered in an almond grove in California. Eradication efforts were begun immediately. In spite of these efforts, by March 1999 it was reported from several locations in six different counties in California (URL h). In March 1999, the California Department of Food and Agriculture placed portions of Riverside and Los Angeles counties under plant quarantine due to the *S.invicta* infestation (URL h).

Invasive attributes:

S.invicta is capable of being extremely invasive due to several biotic factors. Solenopsis are aggressive generalist foragers that occur in high densities, and can thus dominate most potential food sources (Vinson 1994). Its stinging ability allows it to repel even larger vertebrate competitors from resources (Vinson 1994). It is opportunistic and exploits disturbed habitat (Tschinkel 1993). Mated queens can disperse up to a kilometer or more (Lofgren et al. 1975), and colonies are able to disperse on flowing water which gives them an advantage in areas of seasonal flooding (Morrill 1974, in Tschinkel 1993). They can improve the success of colony founding through pleometrosis (the existence of colony founding by more than one queen) and raiding the brood of incipient nests (Tschinkel 1992). Colonies invest heavily in large numbers of reproductive forms, and new colonies undergo rapid exponential growth (Tschinkel 1993). And, sexual production and release occurs over a more extended season than in many other species of ants, occurring during most months of the year in some areas (Rhoades and Davis 1967, Tschinkel 1993, and Lofgren et al 1975, in Tschinkel 1993).

Invaded Ecosystem Attributes:

S. invicta occurs in just about all habitats except swamp and dense forest. It occurs mostly in areas of disturbance such as lawns, pastures, roadsides, and agricultural lands. Areas with a high water table and seasonal flooding are also successfully colonized. *S. invicta* have the capacity, when waters rise, to float as a mat of ants, surviving for weeks until the waters recede or they drift ashore. This adaptation has allowed them to colonize wet savanna areas even in the absence of human disturbance. At least in the U.S., seasonal flooding eliminates most other ant species. (Tschinkel 1993).

S. invicta lacks the ability to hibernate and is thus likely limited by winter-cold or a warm season that is too short for colony development and reproduction (Tschinkel 1993). Little is known about the ants moisture requirements, and whether aridity will limit its spread (Tschinkel 1993). Klein and Thompson (URLa) state that it is able to establish in areas with temperatures above 10°F and rainfall above 10 inches/year. Tschinkel (1993) states that the timing of rain may be as important as the amount, because mating flights and successful colony founding take place only on warm days after heavy rains. Regardless, the presence of human constructs that provide warmth and/or moisture (buildings, irrigated fields, etc) may likely allow this ant to spread into areas with colder and/or dryer climates.

Key contacts in Hawaii:

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Ellen VanGelder (Research Associate, Haleakala National Park Field Station, Biological Resources Division/USGS, P.O. Box 369, Makawao, HI 96768; phone 808-572-4472; email: evangeld@hawaii.edu) Works on Argentine ant control in Haleakala National Park.

Literature references:

Adams, C. T., W. A. Banks, C. S. Lofgren, B. J. Smittle, and D. P. Harlan. 1983. Impact of the red imported fire ant *Solenopsis invicta* (Hymenoptera: Formicidae) on the growth and yield of soybeans. *J. Econ. Entomol.* 76:1129-1132.

Adams, C. T., W. A. Banks, and C. S. Lofgren. 1988. Red imported fire ant (Hymenoptera: Formicidae) correlation of ant density with damage to two cultivars of potatoes (*Solanum tuberosum* L.). *J. Econ. Entomol.* 81:905-909.

Allen, C.R., R. S. Lutz, and S. Demarais. 1995. Red imported fire ant impacts on northern bobwhite populations. *Ecological Applications* 5:632-638.

Banks, W. A. 1994. Chemical control of the red imported fire ants. Pages 596-603 in D. F. Williams (ed.) *Exotic Ants: Biology, Impact, and Control of Introduced Species*. Westview Press, Boulder, CO.

Boock, O. J., and L. G. Lordello. 1952. formiga "Lava-pe" praga de batatinhya- *Solanum tuerosum* L. *Rev. Agric. (Piracicaba)* 27:377-379.

- Brown, R. V. 1982. The State perspective of the imported fire ant. Pages 36-39 in S. L. Battenfield (ed.) Proceedings of the symposium on the imported fire ant, June 7- 10, Atlanta, Georgia.
- Buren, W.F. 1972. Revisionary studies on the taxonomy of the imported fire ants. J. Ga. Entomol. Soc. 7:1-27.
- Buren W. F., G. F. Allen, W. H. Whitcomb, F. E. Lennartz, and R. N. Williams. 1974. Zoogeography of the imported fire ants. J. New York Entomol. Soc. 82:1d13- 124.
- Cokendolpher, J. C. and S. A. Phillips. 1990. Critical thermal limits and locomotor activity of the red imported fire ant (Hymenoptera: Formicidae). Environ. Entomol. 19: 878-881.
- Davidson, N. A. and N. D. Stone. 1994. Imported fire ants. Pages 196-217 in D. L. Dahlsten and R. Garcia (eds.) Eradication of Exotic Pests: Analysis With Case Histories. Yale Univ. Press, New Haven, CT.
- Dickenson, V. M. 1995. Red imported fire ant predation on Crested Caracara nestlings in south Texas. Wilson. Bull. 107:761-762.
- Drees, B. M., L. A. Berger, R. Cavazos, and S. B. Vinson. 1991. Factors affecting sorghum and corn seed predation by foraging red imported fire ants (Hymenoptera: Formicidae). J. Econ. Entomol. 84:285-289.
- Drees, B. M. 1994. Red imported fire ant predation on nestlings of colonial waterbirds. Southwest. Entomol. 19:355-359.
- Flickinger, E. L. 1989. Observations of predation by red imported fire ants on live-trapped wild cotton rats. Texas Journal of Science 41:223-224.
- Fowler, H. G., J. V. Bernardi, and L. F. di Romagnano. 1990. Community structure and *Solenopsis invicta* in Sao Paulo. Pages 199-209 in R. K. Vander Meer, K. Jaffe and A. Cedeno (eds.) Applied Myrmecology: a World Perspective. Westview Press, Boulder, CO.
- Gilbert, L. 1998. Fire ants, armadillos and phorid flies - answers to frequently asked questions. URL: uts.cc.utexas.edu/~gilbert/research/fireants/faq.html
- Gilbert, L. 1999. Using phorid flies in the biocontrol of imported fire ants in Texas. URL: uts.cc.utexas.edu/~gilbert/fireants/fireant.html
- Green, H. B. 1952. Biology and control of the imported fire ant in Mississippi. J. Econ. Entomol. 45:593-597.
- Gust, D. A. 1983. Small mammal populations on reclaimed strip-mined areas in Freestone county, Texas. M.S. thesis, Texas A&M University, College Station, 61pp.

- Killion, M. J., W. E. Grant, and S. Bradleigh Vinson. 1995. Response of *Baiomys taylori* to changes in density of imported fire ants. *J. Mammal.* 76:141-147.
- Killion, M. J. and W. E.. Grant. 1993. Scale effects in assessing the impact of imported fire ants on small mammals. *Southwest. Natur.* 38:393-396.
- Klein K., and L Thompson. a) Fire ant control strategies. URL: uaex.edu/natural/fireant/mp374.htm
- Klein K., and L Thompson. b) Imported fire ant biology. URL: uaex.edu/natural/fireant/fsa7042.htm
- Lennartz, F. E. 1973. Modes of dispersal of *Solenopsis invicta* from Brazil into the continental United States - A study in spatial diffusion. M.S. thesis, University of Florida, Gainesville, 242pp.
- Lockley, T. C. 1995. Effect of imported fire ant predation on a population of the Least Tern - an endangered species. *Southwest. Entomol.* 20:517-519.
- Lofgren, C. S., W. A. Banks, and B. M. Glancey. 1975. Biology and Control of imported fire ants. *Ann. Rev. Entomol.* 20:1-30.
- Lofgren, C. S. 1986. History of imported fire ants in the United States. Pages 36-47 in C. S. Lofgren and R. K. Vander Meer (eds.) *Fire Ants and Leaf-cutting Ants: Biology and Management.* Westview Press, Boulder, CO.
- Markin, G. P., J. O'Neil, and J. Dillier. 1975. Foraging Tunnels of the red imported fire ant, *Solenopsis invicta* (Hymenoptera: Formicidae). *J. Kan. Entomol. Soc.* 48:83- 89.
- Markin, G. P., J. O'Neil, J. Dillier, and H. L. Collins. 1974. Regional variation in the seasonal activity of the imported fire ant, *Solenopsis saevissima richteri*. *Environ. Entomol.* 3: 446-452.
- Masser, M. P. and W. E. Grant. 1986. Fire ant induced trap mortality of small mammals in east-central Texas. *Southwest. Natur.* 31:540-542.
- Maxwell, F. G., W. A. Banks, J. L. Bagent, W. L. Buren, O. Franke, S. J. Risch, A. Sorenson, W. L. Sterling, and J. L. Stimac. 1982. Population dynamics of the imported fire ant. Pages 67-74 in S. L. Battenfield (ed.) *Proceedings of the symposium on the imported fire ant, June 7-10, Atlanta, Georgia.*
- Mirenda, J. T., and S. B. Vinson. 1981. A marking technique for adults of the red imported fire ant. *Florida Entomologist* 62:279-281.
- Morrill, W. L. 1974. Dispersal of red imported fire ants by water. *Florida Entomol.* 57:39-42.
- Morrill, W. L. 1978. Red imported fire ant predation on the alfalfa weevil and pea aphid. *J. Econ. Entomol.* 71:867-868.

- Pimentel, D., L. Lach, R. Zuniga, and D. Morrison . 1999. Environmental and economic costs associated with non-indigenous species in the United States. Cornell University, URL: www.news.cornell.edu/releases/Jan99/species_costs.html
- Porter, S. D., B. Van Eimeren and L. E. Gilbert. 1988. Invasion of red imported fire ants (Hymenoptera: Formicidae): microgeography of competitive replacement. *ann. Entomol. Soc. Amer.* 81: 913-918.
- Porter, S. D., H. G. Fowler, and W. P. McKay. 1992. Fire ant mound densities in the United States and Brazil (Hymenoptera: Formicidae). *J. Econ. Entomol.* 85:1154-1161.
- Porter, S. D. and D. A. Savignano. 1990. Invasion of polygyne fire ants decimates native ants and disrupts arthropod community. *Ecology* 71:2095-2106.
- Porter, S. D. and W. R. Tschinkel. 1987. Foraging in *Solenopsis invicta* (Hymenoptera: Formicidae): effects of weather and season. *Environ. Entomol.* 16:802-808.
- Reagan, T. E., G. Coburn, and S. D. Hensley. 1972. Effects of mirex on the arthropod fauna of a Louisiana sugarcane field. *Environ. Entomol.* 1:588-591.
- Rhoades, W. C., and D. R. Davis. 1967. Effects of meteorological factors on the biology and control of the imported fire ant. *J. Econ. Entomol.* 60: 554-558.
- Ridlehuber, K. T. 1982. Fire ant predation on wood duck ducklings and pipped eggs. *Southwest. Natur.* 27:222.
- Ross, K. G., E. L. Vargo and L. Keller. 1996. Social evolution in a new environment: the case of introduced fire ants. *Proc. Natl. Acad. Sci. USA* 93:3021-3025.
- Ross K. G. and J. C. Trager. 1990. Systematics and population genetics of fire ants (*Solenopsis saevissima* complex) from Argentina. *Evolution* 44:2113-2134.
- Sikes, P. J. and K. A. Arnold. 1986. Red imported fire ant (*Solenopsis invicta*) predation on cliff swallow (*Hirundo pyrrhonota*) nestlings in east-central Texas. *Southwest. Natur.* 31:105-106.
- Smith, T. S., S. A. Smith, and D. J. Schmidly. 1990. Impact of fire ant (*Solenopsis invicta*) density on northern pygmy mice (*Baiomys taylori*). *Southwest. Natur.* 35:158-162.
- Sorenson, A. A., T. M. Busch, and S. Bradleigh Vinson. 1983. Behaviour of worker subcastes in the fire ant *Solenopsis invicta* in response to proteinaceous food. *Physiological Entomology* 8:83-92.
- Sterling, W. L. 1978. Imported fire ant...may wear a gray hat. *Texas Agric. Progress* 24:19-20.
- Stewart, J. W., and S. B. Vinson. 1991. Red imported fire ant damage to commercial cucumber and sunflower plants. *southwest. Entomol.* 16:168-170.

Stoker, R. L. 1992. A hierarchical perspective on the ecology of biological invasions: impact of red imported fire ants on grassland ecosystems. M.S. thesis, Texas A&M University, College Station, 66pp.

Tedders, W. L., C. C. Reilly, B. W. Wood, R. K. Morrison and C. S. Lofgren. 1990. Behavior of *Solenopsis invicta* (Hymenoptera: Formicidae) in pecan orchards. *Environ. Entomol.* 19: 44-53.

Tschinkel, W. R. 1982. History and biology of fire ants. in S. L. Battenfield (ed) Proceedings of the symposium on the imported fire ant, June 7-10, Atlanta, Georgia.

Tschinkel, W. R. 1987. Fire ant queen longevity and age: estimation by sperm depletion. *Ann. Entomol. Soc. Amer.* 80:263-266.

Tschinkel, W. R. 1992. Brood raiding and the population dynamics of founding and incipient colonies of the fire ant *Solenopsis invicta*. *Ecol. Entomol.* 17:179-188.

Tschinkel, W. R. 1993. The fire ant (*Solenopsis invicta*): still unvanquished. Pages 121- 136 in B.N. McKnight (ed.), *Biological Pollution: The Control and Impact of Invasive Exotic Species*. Indiana Academy of Science, Indianapolis, IN.

Tschinkel, W. R. and S. D. Porter. 1988. The efficiency of sperm use in queens of the fire ant, *Solenopsis invicta* Buren. *Ann. Entomol. Soc. Amer.* 81:777-781.

Tschinkel, W. R., E. S. Adams, and T. Macom. 1995. Territory area and colony size in the fire ant *Solenopsis invicta*. *J. Animal Ecol.* 64: 473-480.

URL a. University of Arkansas, Division of Agriculture, Cooperative Extension Service. Red Imported Fire Ant Homepage. URL: uaex.edu/natural/fireant/firehome.htm

URL c. University of Arkansas, Division of Agriculture, Cooperative Extension Service. Red Imported Fire Ant Homepage. URL: uaex.edu/natural/fireant/history.htm

URL d. University of Arkansas, Division of Agriculture, Cooperative Extension Service. Red Imported Fire Ant Homepage. URL: uaex.edu/natural/fireant/quar.htm

URL e. Texas A&M University, Department of Entomology, Imported Fire Ant Website. URL: fireant.tamu.edu/plan/index.html

URL f. Texas A&M University, Department of Entomology, Imported Fire Ant Website. URL: fireant.tamu.edu/management/index.html

URL: g. Purdue University, Center for Environmental and Regulatory Information Systems, National Agriculture Pest Information Systems Website. URL: ceris.purdue.edu/napis/pests/ifa.

URL h. California Department of Food and Agriculture, Red Imported Fire Ant Web page. URL: cdfa.ca.gov/pests/fire_ants/new/index.html

- Vinson, S. B. 1972. Imported fire ant feeding on Paspalum seed. *Am. Entomol. Soc. Am.* 65:988.
- Vinson, S. B. 1991. Effect of the imported fire ant (Hymenoptera: Formicidae) on a small plant-decomposing arthropod community. *Environ. Entomol.* 20: 8-103.
- Vinson, S. B. 1992. The economic impact of the imported fire ant infestation on the State of Texas. Report. College Station, TX: Texas A & M University.
- Vinson, S. B. 1994. Impact of the invasion of *Solenopsis invicta* (Buren) on native food webs. Pages 241-258 in D. F. Williams (ed.) *Exotic Ants: Biology, Impact, and Control of Introduced Species*. Westview Press, Boulder, CO.
- Williams, D. F. 1994. Control of the introduced pest *Solenopsis invicta* in the United States. Pages 282-292 in D. F. Williams (ed.) *Exotic Ants: Biology, Impact, and Control of Introduced Species*. Westview Press, Boulder, CO.
- Wilson, E. O. 1978. Division of labor in fire ants based on physical castes. *J. Kan. Entomol. Soc.* 51:615-636.
- Wilson, N. L., J. H. Dillier, and G. P. Markin. 1971. Foraging territories of imported fire ants. *Annals of the Entomol. Soc. of America.* 64: 660-665.