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Approaches to Biological Control of Fire Ants in the United States

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INTRODUCTION

The red and black imported fire ants, *Solenopsis invicta* Buren and *Solenopsis richteri* Forel, have been extremely successful immigrants to the United States. Since the first infestation was noted at Mobile, Alabama in 1929, they have spread to ca 10^8 ha in 11 southeastern states and Puerto Rico (Lofgren, 1986). In recent years their rate of spread has slowed, for they are approaching their ecological limits in the Southeast (Francke and Cokendolpher 1986). Recently they have been accidentally moved by man across the arid southwest to Arizona (Frank 1988) and California (C.S. Lofgren, Personal communication). Should they become established in the west, their range will increase substantially. In addition, a polygynous form with denser populations, and which is sometimes more difficult to control, is spreading. However, the diminished territorial behavior of polygynous colonies may render them more vulnerable to biotic agents.

The growth of the imported fire ant infestation in the United States has not gone unopposed. As medical and agricultural pests, they have been assaulted with a succession of pesticides by Federal and State agencies at a cost (by 1976) of well over $100,000,000. Despite these efforts, the United States has more fire ants than ever, and their numbers are increasing. Pesticides, although useful for temporary local suppression, cannot provide a permanent solution to the fire ant problem in the United States. It is possible, however, that biological control may provide a permanent amelioration of the problem.

Unfortunately, fire ants are difficult subjects for biological control. Serious obstacles are posed by the longevity (Tschinkel 1987), protected environment (see "Biological Insecticides" below) and high reproductive potential (Morrell 1974) of their queens. In addition, fire ants are ecological generalists able to exploit a wide variety of habitats and environmental conditions. Their ability to exploit disturbed environments led Tschinkel (1986) to characterize them as a "weed" species. Such versatility can only add to the complexity of biological control.

APPROACHES TO BIOLOGICAL CONTROL OF FIRE ANTS

Research to date on biological control of fire ants can be divided into: 1) evaluation of non-specific natural enemies for use as biological formicides (temporary local suppression) and 2) the search for specific natural enemies for introduction into the United States (permanent reduction of the pest population).

Biological Insecticides.

Efficacious formicides are those chemical or biological agents which destroy an ant colony's reproductive capacity (kill or sterilize the queen or queens). Agents which only kill worker ants do not effectively eliminate colonies, although they may temporarily reduce their size. This requirement is a serious obstacle to the development of a biological formicide. Fire ant queens are sequestered in subterranean nests and surrounded and defended by tens of thousands of aggressive workers. They are groomed meticulously, and fed highly filtered, regurgitated liquids (latex microspheres as small as 0.88 um are filtered by workers - Glancey et al. 1981; the microflora of the queen's gut is highly restricted or absent - Jouvenaz, unpublished). As adults, they are refractory to infection by many entomopathogens. Furthermore, fire ants fumigate their nests with venom (Obin and Vander Meer 1985), which has antibacterial and antifungal properties (Jouvenaz et al. 1972; Cole 1975). Although it may be possible to overwhelm these defenses with massive doses of a biotic agent, fire ants frequently relocate their nests to escape the presence of foreign organisms, or simply in response to disturbance (Jouvenaz and Lofgren 1986).

One arthropod and many non-specific entomopathogens have been evaluated as possible biological formicides for fire ants. The straw-itch mite, *Pyemotes tritici*, was considered promising by Bruce and Le Cato (1980), and for a time was even marketed by at least two firms. However, subsequent evaluations by Jouvenaz and Lofgren (1986), Thorvilson et al. (1987), and Collins (USDA-APHIS; personal communication) failed to demonstrate a useful degree of efficacy. The mites are also hazardous to handle; they can cause dermatitis severe enough to require medical treatment or even hospitalization (Baggett et al. 1981).

The non-specific entomopathogens that have been evaluated for use as microbial formicides include the bacteria *Bacillus thuringiensis, B. sphaericus, Serratia marcescens, Pseudomonas aeruginosa* and *P. chloroaphis* (Broome 1974; Miller and Brown 1983; Jouvenaz, unpublished), fungi of the genera *Beauveria* and *Metarrhizium* (Broome 1974; Quattlebaum 1980; Stimac et al. 1987), microsporidia of the genera *Nosema* and *Thelohania* (Jouvenaz, unpublished), several strains of the nematodes *Neoaplectana carpocapsae* and *Heterorhabtidis heliothidis* (Quattlebaum 1980; Poole 1976; Jouvenaz, unpublished), and various baculoviruses (Broome 1974). The honey bee pathogens, *Bacillus larvae*, *B. pulvifaciens*, and honey bee paralysis virus were also tested (Jouvenaz, in press). With the possible exception of *Beauveria* spp. isolated from fire ants in Brazil (Stimac et al. 1987), none of these organisms have produced significant fire ant control under laboratory and/or field conditions.

Specific Natural Enemies.

In the United States, imported fire ants are essentially free of specific natural enemies (Jouvenaz et al. 1977). In their native South America, however, they are beset by a complex of pathogens: parasites, social parasites and symbiotic predators. Although we are aware of many of these organisms, we as yet know little of their biology, impact on individual colonies or field populations of fire ants, or their environmental safety (Jouvenaz 1986; Wojcik et al. 1987).

A large number of arthropods have been observed in fire ant colonies (see D. P. Wojcik this volume), but many appear to be commensals. Predacious symbionts such as the beetle, *Martinezia dutertrei* (Scarabaedae), and parasites such as *Orasema* spp. wasps, do destroy immature fire ants; however, their numbers are invariably very low relative to their host population, and their direct impact is therefore limited. There are sound biological reasons to suspect that some of these symbionts may be vectors of ant disease (Jouvenaz 1986).

Among arthropods, the socially parasitic ant, *Solenopsis (Labauchena) daguerri* Santschi, appears to be the most promising candidate for introduction. Queens of this workerless species integrate into fire ant colonies, where they and their offspring are cared for (apparently preferentially) by their hosts. The parasites do not contribute to the economy of the colony, and under the burden of these unproductive individuals colony vigor declines. Possibly as a result of nutritional deprivation, the oviposition rate of the host queen decreases, the proportion of major workers diminishes, and sexual forms disappear. The workers become less aggressive and allow the nest to deteriorate. Heavily infested colonies (*S. daguerri* may constitute over 70% of the total population) can readily be identified by their eroded and unrepaired nest tumuli. The process of debilitation may take two years, but ends with collapse of the colony (Silveira-Guido et al. 1973).

Solenopsis daguerri is the only natural enemy known to destroy established fire ant colonies. It is discouraging that *S. richteri* populations in Argentina can be quite high in areas where *S. daguerri* is common (Silveira-Guido et al. 1973), since this is not indicative of biocontrol. However, we do not understand the population dynamics of fire ants in their native ranges (Wojcik 1986); The parasite infestation could have been recent and later have led to collapse of the fire ant population. In a different ecosystem, *S. daguerri* might be a valuable member of a complex of natural enemies of fire ants.

Phorid flies, *Pseudacteon* spp. and an *Apodicrania* sp., are endoparasites of fire ants in South America (Williams and Whitcomb 1974). The number of ants parasitized by these flies is relatively low; however their impact on fire ant populations may be much greater than that due to simple parasitism. Feener (1981) reported that the presence of a phorid fly, *Apocephalus* sp. shifts the competitive balance between *Solenopsis texana* and *Phidole dentata* by interfering with the defensive behavior of major workers of the latter. In the absence of phorids, *P. dentata* dominated food sources. In the presence of phorids, however, *S. texana* was able to dominate food sources because *P. dentata* major workers retreated from the flies. The presence of phorids that specifically parasitize fire ants could provide an advantage to competitive native ant species.

The subject of competition between ant species brings us to the most radical strategy yet proposed for biological control of fire ants. Buren (1983) suggested that the solution to the fire ant problem in the United States is competitive displacement by a complex of deliberately introduced predator and competitor ant species. Buren called his hypothetical complex an "artificial" ant fauna. I prefer the term "selected" ant fauna.

The introduction of exotic ant species is potentially hazardous; without careful selection of candidate species based on thorough research, pest ant problems could be compounded. Replacing one dominant ant species with another is unacceptable. Rather, for ecological stability, Buren envisioned a complex of 20-30 species, the composition of which would vary geographically. Thus, the selected ant faunas of southern Florida and northern Mississippi would have some, but not all, species in common. Buren assumed a beneficial ant fauna could be selected that was at least not harmful to major elements of our native flora and fauna (some displacement of native ant fauna would be inevitable, but much displacement by imported fire ants has already occurred). All species selected would have to be beneficial, or at least innocuous, to man and agriculture.

Buren discussed the characteristics that would govern the selection of species for study and concluded that several hundred to a thousand candidates exist world-wide (it is not necessary, or perhaps even desirable, for the candidates to be sympatric with fire ants). Buren also addressed the approaches and methodologies that might be employed in evaluating these candidates. Unfortunately, the thorough evaluation of so many exotic ant species would be expensive and very time consuming. Obtaining approval to import exotic ants for release, even after extensive research, might prove difficult.

Despite obvious technical difficulties and the potential for environmental harm, Buren's proposal may have merit, especially in concert with a complex of specific natural enemies. The primary role of host-specific natural enemies may be to stress fire ants, thereby reducing their competitive fitness. Hopefully, these specific natural enemies will enable native ants to displace fire ant populations to a significant extent. Should exotic ants be required, pathogens and parasites might at least reduce the number of species needed.

CURRENT USDA BIOLOGICAL CONTROL RESEARCH

The primary goal of the USDA biological control of fire ants research program is the establishment of a complex of specific natural enemies of fire ants in the United States that will be of value in an integrated pest control program. Even a modest reduction in fire ant populations should reduce or eliminate the need for pesticide treatments in large areas. The development of biological insecticides is a secondary goal of this program.

The initial phase of USDA research was exploration - the discovery and description of the specific natural enemy biota of fire ants. The known pathogen biota now includes a virus, at least three endoparasitic fungi, six protozoans, and three nematodes; other pathogens doubtless remain to be discovered. Although the majority are probably commensals, ca 200 species of arthropods have been associated with fire ants (see Wojcik in this volume). The emphasis of research is now on the biology and impact of these organisms. A thorough understanding of their pathobiology or life cycles, host ranges (= environmental safety) and an estimate of at least their relative potential impact on fire ant populations is required for the selection of candidates for introduction. It is difficult to predict the impact of a biological control agent in a new environment; environmental safety, however, must be accurately assessed. For this reason, we are currently studying only those organisms whose host range appears to be limited to *Solenopsis* spp. For those candidates selected and approved for introduction, it will be necessary to develop techniques for mass production and quality control, dissemination, and monitoring of spread and impact. Possible interactions of the agent with control practices may also need to be assessed.

We have selected the socially parasitic ant, *S. daguerri*, the nematode *Tetradonema solenopsis* Nickle and Jouvenaz (1987), and three undescribed, endoparasitic fungi for concentrated study. We have also begun monitoring fire ant and arthropod symbiont population dynamics and epizootiology in the field through the USDA Biological Control of Weeds Laboratory, Hurlingham, Argentina.

Solenopsis daguerri, as noted above, is the only natural enemy known to destroy established fire ant colonies. As an obligate (workerless) social parasite that is at least genus specific, it is environmentally safe. However, the very specificity of *S. daguerri* for its host may present difficulties in establishing it in a new host population. In the 1960's, Uruguayan entomologists repeatedly attempted to introduce *S. daguerri* from Argentina without success. These efforts only involved moving material by air in one day from Buenos Aires to Montevideo, and then to areas of eastern Uruguay heavily infested with *S. richteri* (personal communication, M. S. Blum, University of Georgia). We do not know what procedures they employed to collect, handle, or disseminate S. daguerri; the failure may have been due to the parasite's inability to integrate into a new host population. The major mechanism of symbiont integration into fire ant colonies appears to be chemical mimicry (Vander Meer and Wojcik 1982; Vander Meer et al. 1989). A difference in the cuticular odors of parasite and new host may prevent integration. If this is the case, a technique must be developed to precondition *S. daguerri* (or a sibling species) for acceptance by North American fire ant populations.

The nematode *T. solenopsis* parasitizes *S. invicta* and was found in the states of Mato Grosso and Mato Grosso do Sul, Brazil. Adult male and female nematodes, eggs, and juveniles occur together in adult worker ants, but the life cycle and mode of transmission are unknown. Presumably juveniles emerge from the host to mature and mate in the soil, and then infect a new host. Interestingly, the distribution of nematodes in the colony is non-Poisson. Multiple (up to 35) adult females, plus many males are found in individual worker ants from colonies having infection rates of less than 5% (Jouvenaz et al. 1988). Therefore, we hypothesize that the invading inseminated parasite produces a limited number of offspring (both males and females) which become the "reproductive group." The offspring of the reproductive group then produces large numbers of offspring which infect new hosts. We cannot gain insight into the life cycle of *T. Solenopsis* from the five other known species of Tetradonematidae; the life histories of these parasites of Diptera and Coleoptera are also poorly known. *Tetradonema solenopsis* is extremely stressful to its host, and we have been unable to maintain infected colonies in the laboratory. Colonies with infection rates above 25% have been collected (most are below 5%), but infected individuals rapidly died. Our immediate goal is to culture infected colonies in soil, and transmit the infection to healthy colonies through nematode-infested soil. Success will enable us to determine host specificity and, hopefully, elucidate the life cycle. If adult queens are susceptible to infection, the nematode could destroy established fire ant colonies.

Four species of endoparasitic fungi occur as budding yeasts in the hemolymph of fire ants. At least one species appears to be an obligate parasite, for it grows very slowly *in vitro*. These fungi can be mass-produced inexpensively, have been transmitted *per os* to *S. invicta*, and we are optimistic that at least the obligate parasite will prove host-specific for *Solenopsis* spp. Our observations to date indicate that they are simply nutritional burdens to their hosts, producing no toxins, gross pathology or histopathology. They are prime candidates for genetic engineering. If a way can be found to preserve the invasive ability of these fungi (which declines during *in vitro* culture), it may be possible to alter them genetically to produce toxins of our choice, juvenile hormone or other hormones, or perhaps even semiochemicals to disrupt colony organization. We have determined that the obligate parasite is susceptable to the antibiotic hygromycin B, for which a cloned resistance gene is available. A model transformation test for hygromycin resistance will be conducted when taxonomic studies in progress are complete, and the experiment is approved by the biotechnology committee. Even without genetic modification, they may prove valuable as stressing agents in concert with other natural enemies or control practices. The endoparasitic yeasts are the only specific pathogens of fire ants which appear to have potential for both development as a microbial formicide and establishment in our ecosystem.

Biological control of fire ants is a formidable task. meeting the challenge requires time and resources for in-depth, innovative basic and applied research, particularly if permanent amelioration of the problem is to be achieved. Biotechnology, in particular, presents exciting prospects for the development of genetically engineered microbial insecticides, and for more virulent, well-adapted symbiotic microorganisms. The alternative is to limit ourselves to the recurrent expenses of temporary, local suppression, and to accept an ever-increasing fire ant problem in the United States.

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