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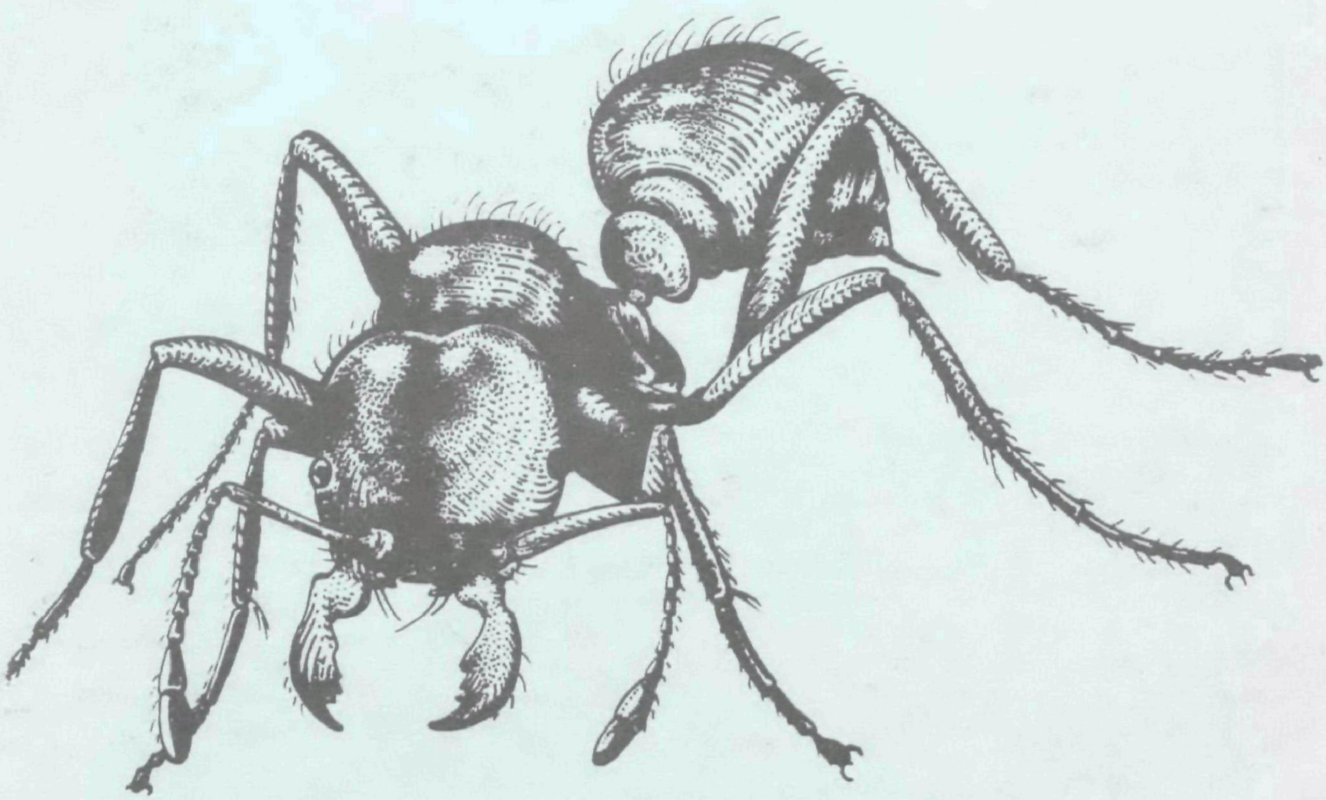
Proceedings of the Symposium on the Imported Fire Ant

June 7-10, 1982
Atlanta, Georgia



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PROCEEDINGS OF THE
SYMPOSIUM ON THE IMPORTED FIRE ANT

June 7 - 10, 1982

ATLANTA AMERICAN HOTEL

ATLANTA, GEORGIA

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ORGANIZED AND MANAGED BY:

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ACKNOWLEDGEMENTS

There are always many who contribute to the success of any endeavor. That is especially true for the Imported Fire Ant Symposium because its conception, gestation, and birth occurred in such a short time. Labor pains were particularly intense for panel chairmen. They were first contacted during the last full week in March. That they agreed readily to devote time to an important public issue commends their professionalism and their sense of responsibility to society. We are grateful for their efforts. Equal dedication was exhibited by panel members. The Symposium would not have been possible without the time and talent they contributed so unstintingly. All chairmen and members of panels are listed in the appropriate panel reports. We owe each a debt of gratitude.

The unsung heroes of any large meeting are always those who arrange the amenities most of us take for granted. Travel arrangements, hotel accomodations, meeting rooms, and a host of other details don't simply happen. They were provided by the untiring efforts of the business office of the Inter-Society Consortium for Plant Protection, in the persons of Raymond Tarleton and his able, ever pleasant assistant, Dottie Ginsburg. A principal factor in keeping the Coordinator coordinated was my secretary, Doreen Kebler. Her assistance was invaluable.

Attention to numerous details during the Symposium, editing, and processing this report required the sure touch of Susan Battenfield. Panel reports written rapidly and under stress during the course of the Symposium necessarily required editorial skill. The results of Susan's efforts are apparent. Her assistance was invaluable.

Lastly, the genesis and support of the Imported Fire Ant Symposium came from the Environmental Protection Agency and the Animal Plant Health Inspection Service of the U.S. Department of Agriculture. That they recognized the fire ant and its management as a serious scientific, social, and political issue was expected. That they joined forces to host a Symposium at which the many diverse attitudes and points of view relating to management of the fire ant could be discussed openly was not expected. Their willingness to risk criticism in an open forum signifies a maturity of judgment and an awareness of social responsibility that augers well for the resolution of honest disputes in the future. We commend their action and hope that other agencies, organizations, and groups, whether they be governmental, the federal, state or local level, or in the private sector, will recognize the

value of open discussion of differences in a spirit of resolving disputes rather than perpetuating them through an adversarial process.

Many others contributed importantly to the success of the Symposium. Failure to mention their contributions does not reflect insensitivity to their help, rather a constraint of time and space. We are indeed grateful to all.

Fred H. Tschirley
Coordinator

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EXECUTIVE SUMMARY

Fred H. Tschirley

INTRODUCTION

The imported fire ants (IFA), *Solenopsis richteri* Forel and *Solenopsis invicta* Buren were introduced from South America into the United States in the early 1900's and the late 1930's, respectively, at the port of Mobile, Alabama. Their area of infestation has expanded dramatically since introduction. In the late 1940's and early 1950's, they were present from Miami, Florida, west to San Antonio, Texas, and north to Memphis, Tennessee, and eastern North Carolina. Today, they are found on about 240 million acres in 10 states. *S. invicta*, the red fire ant, occupies over 95% of the infested area; *S. richteri*, the black fire ant, is found in northern Mississippi and Alabama. The spread of the IFA has occurred despite extensive state and federal programs designed for its control.

The potential future distribution of the IFA is open to some question. There is general agreement that northward extension of the present area of infestation has reached its limit, although some extension may occur along the eastern coast. Westward spread cannot be accurately predicted because all of the biotic and abiotic factors influencing establishment are not known. Warm rains, which occur in New Mexico and Arizona, are necessary to trigger mating flights and ensure nest excavation. Southern California lacks summer rains, but has extensive irrigation acreage that may trigger mating flights. Thus, expansion of the IFA range westward to California and then northward along the coast through Oregon and Washington is not certain, but neither is it improbable.

NATURE OF THE PROBLEM

IFA infestations occur in many habitats: field and vegetable crops, nurseries, orchards, hay fields, forests, and unmanaged wildlands. That the IFA is a pest is unquestioned; that it is truly an economic pest of agriculture has not been adequately documented.

Data concerning the agricultural impact of the IFA do not support a conclusion of its being an economic pest, although reports indicate livestock losses from IFA stings. Other reports document reductions in hay yield and quality, and yield reductions for field crops (soybeans) where ants are abundant or where seed has not been well covered at planting. Damage to equipment and conversion to alternate harvesting equipment (hay, for example) due to IFA mounds are unquestioned adverse economic impacts. The IFA are a nuisance for crops that are hand-harvested, but no studies have documented the economic impact of this factor. On the other hand, the IFA is considered to be a key predator of *Heliothis* species in cotton production, is an excellent predator of the sugarcane borer (saving growers one or two insecticide applications per season), preys on the banded cucumber beetle and sweet potato weevil in sweet potatoes, and is an important predator of many detrimental insects in soybeans. The IFA is also an excellent predator of ticks, hornflies, and stable flies. In many areas IFA predation has reduced lone star tick populations to the point where they are no longer considered to be an economic pest.

Although costs and benefits of IFA in agriculture have been documented, the available data base is too limited to permit a conclusive cost/benefit analysis. An economic analysis of one county in Florida established a cost/benefit ratio of 5.6:1, but the extent to which that study can be extrapolated to other agricultural areas is unknown.

Young birds and other forms of wildlife that nest on or in the ground are vulnerable to IFA attack during their early hours of life. There are documented cases of young quail and newly born rabbits being killed by the IFA, but there is no indication that populations of those species have been reduced.

Human health consequences may be the most important adverse effect of IFA infestations. Because urban as well as rural areas are infested, about 40 million people are in potential conflict with the IFA. The IFA was so named because the venom induces a painful, fiery sensation. The ant grips the skin with its mandibles and may sting its victim multiple times in a circular pattern around the point of mandible attachment. The aggressive nature of the ant when a mound is disturbed commonly results in attack by numerous ants so that 10 to 30 stings are common. Many people experience only local reaction and temporary discomfort. In others a sterile pustule develops within 24 hours, which is clinically diagnostic. Although the venom is bactericidal, secondary infections as a result of scratching may occur. A small percentage of persons stung, probably 1% or less, experience a systemic anaphylactic reaction of variable severity. Some such individuals may require hospitilization, and the reaction may be life threatening. One author cites 17 deaths due to fire ant venom. Hypersensitive individuals can be desensitized.

The perceived severity of the IFA as a nuisance or public health pest problem was delineated in two telephone surveys conducted by the American Cyanamid Corporation in 1980 and 1981. The surveys indicated that about one million households treated with insecticides for IFA control; the balance (22%) were using gasoline, boiling water, or cultural methods; 73% of the respondents treated lawns, 58% gardens, 54% pastures, 19% row crops, and 4% woods. The higher percentages recorded for lawn and garden treatment suggest that nuisance and public health reasons are the primary motivations for treatment because an economic return would not be expected for those habitats, especially lawns.

PESTICIDES FOR IFA CONTROL

Large-scale eradication programs for the IFA were initiated in 1958. Heptachlor and dieldrin were applied at a rate of 2 lb. per acre (later reduced to 1.25 lb. per acre) to about 20 million acres over a 5-year period. Effects on wildlife species were disastrous and were a significant reason for public disenchantment with the use of pesticides. Despite the massive eradication attempt, the area infested by the IFA increased from 90 to 126 million acres during the 5-year period.

Mirex, applied in a bait, represented a decided improvement over the previous treatments because the rate of the active ingredient could be reduced to 1.7 grams per acre (0.00374 lb. per acre) without reducing IFA control. A massive eradication program, over a 12-year period, on the entire 126 million acre area of infestation was planned at a cost of $200 million. Problems arose, however, when mirex was found to be persistent in the environment, bioaccumulative, and later shown to cause hepatocarcinomas in mice. Subsequently, the use of mirex was lessened until 1978 when all insecticidal uses were cancelled.

Ten insecticides are currently registered for IFA control by broadcast application on non-agricultural crops, for mound treatment, and for treatment of nursery stock; several have conditional registration or have registration pending. In addition, five insect growth regulators are being developed for possible use as IFA control agents. More detail for the products is provided in Appendix I. The toxicant of greatest concern is ferriamicide. Mirex is the active ingredient in ferriamicide, but the formulation contains amine and ferrous chloride components to reduce environmental persistence and propylene glycol to suppress the production of chlordecone, a degradation product. Ferriamicide does indeed have a shorter environmental half life; however, the presence of chlordecone in shelf samples and the discovery that photomirex is a degradation product of ferriamicide immediately caused concern. Both chlordecone and photomirex are highly toxic and carcinogenic in test animals.

CURRENT MANAGEMENT OPTIONS

The technology now available for managing the IFA in a variety of habitats is limited. Insecticides are the primary management tool; 16 are now registered for one or more uses of which two have state registrations under Section 24(c) of the FIFRA, and 3 have experimental use permits. Seven have a registration or a request for an experimental use permit pending. Boiling water is appropriate for some limited situations. Mound leveling can be effective, but the necessity for timing the treatment just before freezing temperatures occur limits the effectiveness of the method severely.

There is agreement that an educational program needs to be conducted to ensure that necessary and accurate information about the IFA is available to the public. The need is dictated by the fact that the IFA is an emotional issue; therefore, accurate, objective, and unsensationalized information assumes even greater importance. In all educational efforts, a distinction should be made between perceived problems and demonstrable effects.

THE ENIGMA

The red fire ant has been in the U.S. for about 50 years. Serious efforts to control or eradicate the pest have occured during the last 25 years. Despite the passage of time and the expenditure of more than $100 million of local, state, and federal funds to control the IFA, the area of infestation is larger than ever before and is growing. Moreover, the magnitude of the IFA problem cannot be defined with any degree of precision. There are both costs and benefits to agriculture associated with the presence of the IFA. In urban situations, where there is a greater probability of IFA/human contact (and therefore conflict), the IFA has no demonstrated benefits, but the costs in terms of public health considerations are not inconsequential. Some half dozen chemicals used for IFA control have been cancelled, others are currently registered for specific situations, and still others are in the developmental process with hope of eventual registration. Biological control of the IFA is not now possible; physical and cultural manipulation, once thought to deter colony establishment, now appear to be generally ineffective; flooding and burning do not destroy or kill IFA colonies. Integrated pest management, defined as the use of a variety of management methods, can only be applied intellectually because only chemicals have given temporary relief. Nevertheless, logic dictates that some non-chemical control is operating. Mound density varies within the range of infestation, even in disturbed areas that are known to be more readily invaded. Present knowledge, however, cannot identify the operative factors.

In terms of information presented, the IFA Symposium was more notable for its exposition of what is not known but needs to be known, than for what is known—a humbling comment on the wisdom of humans. Consider if you will (1) Panel I's two-plus pages listing the types of data needed to estimate the costs and benefits associated with the IFA; (2) twelve specific research recommendations in Panel III for developing information that must be known before informed management strategies can be applied in a diverse set of habitats; (3) seven specific recommendations by Panel IV to elucidate toxicologic questions relating to the IFA venom and to insecticides used for control; and (4) another seven recommendations from Panel VI, which quickly discovered that chemicals are the only proven technology available for management! Adding the recommendations of Panels II and V, whose subject matter was much broader than just the IFA, completes the litany of the unknown. How can one avoid being impressed, annoyed, frustrated, and dumbfounded by such a comprehensive exposition of our ignorance?

The litany of the unknown should not cast a shadow of reproach on research that has been done on the chemistry of the toxin, the biology of the IFA, and methods for its control. The literature on the IFA contains numerous papers describing exemplary research, which forms the basis for what we know about the IFA today. In addition, carefully crafted research programs have been recently initiated that have promise of soon answering many of the questions that remain unresolved. A valid criticism of past efforts is that research lagged far behind action programs. Even today, many states within the area of infestation do not have an active IFA research program. Only recently has there been a comprehensive review of IFA research, which forms the basis for a research effort that is broader in scope and addresses critically important areas of knowledge that are now wanting.

FUTURE DECISION-MAKING

A message coming through clearly from the symposium is that population and community dynamics of a pest, whether native or introduced, involve an extremely complex interaction of biotic and abiotic components. Any program designed to deal with a pest, whether it be doing nothing on one extreme to eradication attempts on the other extreme, carries an element of uncertainty and may result in failure. The probability of failure necessitates conducting an integrated research program concurrent with the earliest management programs. The management program must be flexible in the sense of changing strategies as knowledge of the pest and its interactions with its environment evolves.

This does not imply that decision-makers should or will have the luxury of doing nothing until adequate knowledge is developed to permit an adequately informed course of action. It does mean that decision-makers should anticipate the possibility of major modifications based on the information developed by a concurrent research program, rather than establishing policy (a plan to deal with a pest) and then designing a research program that supports the policy.

The importance of early detection of a pest is paramount. A new pest that is geographically restricted and numerically limited may be handled relatively easily. There are notable examples of successful pest eradications while the pest's geographic range of infestation was still limited. The failure of eradication efforts against pests that were widely established are equally notable. In that context, the fact that about 84% of newly-detected homopterans in California originated from urban infestations is a matter of prime importance (Appendix O). It begs the question of whether monitoring efforts for new pests should be concentrated in urban areas. If data for homopterans can be extrapolated to other pests species, we must also consider that eradication will be more difficult in densely populated areas. Moreover, by the time a serious pest is detected in an agricultural area, the population may already be sufficiently large and geographically extensive to severely limit management options.

Our society has a reputation of being overly enamored with "quick-fix technology." Define the mouse and we'll build a better mousetrap. That sort of engineering approach to resolving problems is fraught with many difficulties when applied to the biological realm. The quick-fix is, however, an important component of our society's consciousness. Its power as a driving force must be recognized. Persons affected by a perceived threat, whether relief from a nuisance or protection from an economic or public health threat, demand action. Those who provide funding at the local, state, and federal levels to support programs in response to public demands are mightily attracted by quick-fix technology because it promises to solve the problem quickly. Even if the problem is not resolved, the overt show of force that characterizes quick-fix solutions demonstrates a responsiveness to public concerns.

Modifying the quick-fix response by public decision-makers will not be easy. Single-issue politics is a potent force in our society. Would public decision-makers in the early and mid 1950's have survived a decision to allocate funds equitably between an action program and a comprehensive research program on the IFA? The question is rhetorical, but important. The wisdom of hindsight permits the conclusion that, had an equitable allocation of funds between research and eradication occurred in the 1950's, the IFA would probably still be a problem, but most likely it would not be the pervasive scientific-social-political issue that it is today.

Because so much is yet unknown about the IFA, a decision on fund allocation now is not substantially different than it would have been in the 1950's. We, however, do have the advantage of knowing that the eradication attempt was not successful.

Yet the problem of the IFA remains and its geographic range of infestation will probably spread beyond its current limits. What an ideal opportunity, having the IFA Symposium for support, to develop an action-education-research program designed by the best minds available from the scientific, educational, social, and political sectors. A good beginning has been made toward establishing communication among the various sectors of society involved in the fire ant issue. If that communication is now aborted, the IFA Symposium will have been just another meeting of concerned citizens without any perceivable impact on the affairs of humans.

One looks to the future and wonders what and how decisions will be made about the inevitable serious pest we will have to deal with in the years ahead. The agencies that supported the IFA Symposium have a stake in the unknown pest scenario of the future. While EPA's primary responsibility relating to pests is the registration of pesticides, the agency also has a responsibility to comment on environmental impact statements. It cannot do so intelligently without an acute awareness and appreciation for biology and all its complexities—the data needs and the correct questions to be asked for informed decision-making. USDA has broad responsibilities for research and education relating to pests, and it is directly involved in conducting quarantine, pest management, and eradication programs. The decisions USDA must make are difficult scientifically, socially, and politically. Decisions must be based on sound knowledge of biological and ecological components. Both agencies can benefit from drawing on the large and diverse body of expertise resident in the land-grant college system and other academic institutions. Decisions made in isolation are breeding grounds for dispute. Decisions based on a broad foundation of knowledge are much more likely to avoid dispute.

The process of direct communication

among those with different opinions on how to manage the fire ant, which was the guiding principle of the IFA Symposium, provided encouraging indicators that disputes can be resolved through discussion of differences in a non-adversarial setting. Occasional sharp exchanges among those with differing points of view were welcome events. Such exchanges must occur before understanding of a different position and then resolution of differences are possible. Clearly, neither broad scale eradication attempts by using insecticides nor a complete cessation of chemical control are tenable management options for the IFA. That a single symposium will heal the wounds inflicted over many years of adversarial strife is a vain and overly sanguine expectation, however. Dialogue among disputants must continue and expand if the success of the IFA Symposium is to have lasting impact.

Guidelines for decision-making relating to the IFA, to other current pests, and those of the future are contained as recommendations in the panel reports of the IFA Symposium. I commend to you those recommendations. The broader issue, implicitly addressed by the Symposium, is a methodology for dispute resolution. Dispute cannot and should not be avoided; our ability to resolve dispute must be at the top of society's priority list. To that end, the IFA Symposium has been a hopeful beginning.

Opening Remarks

WELCOMING REMARKS

Charles R. Jeter
EPA Regional Administrator
Atlanta, Georgia

Welcome to Atlanta, the fire ant capital of the world, at least for this week. Seriously, the Intersociety Consortium has put together a very impressive program. It is my hope that we will end the week with some answers on how to deal with the imported fire ant problem. The experts are here. It should be a productive week.

I will not take much of your time, but I would like to take this opportunity to remind you that the overriding mission of the Environmental Protection Agency is to safeguard the health of the American people and to protect our natural environment. This is the mission for which EPA was founded and the cause to which this Administration is dedicated. Good science is one of the Agency's goals. That, along with regulatory reform, improved management, elimination of backlogs and strengthened partnerships with state and local governments, will help us fulfill our mission.

Good science is a key element. We believe that there cannot be good regulation without good science. Without adequate scientific understanding, steps necessary for the protection of human health might never be taken.

Our concern for better application of science has led to a more comprehensive involvement of EPA's science advisory board in the development of new regulations. This body of eminent American scientists will be asked to review the scientific adequacy of Agency regulations and generally become more involved in Agency activities. As part of this new approach to the better use of information we are aggressively seeking peer review of Agency scientific reports.

Other actions in this area include the preparation of health assessments for seven chemical solvents. The information will be submitted to the Science Advisory Board for public and peer review. Several other projects that influence the Agency's approach to health and risk assessment are in varying stages of completion.

We've made significant gains in the other areas mentioned earlier, but there's no time to elaborate. I wanted especially to mention our attempts to improve the quality of our science and to underscore that EPA now insists that any proposed regulation whose rationale depends on scientific assumptions is subjected to a thorough peer review by knowledgeable scientists to test the validity of those assumptions.

Again, welcome to Atlanta. Come visit the regional office while you're here. And have a good meeting. Thank you.

OPENING REMARKS

John Ferris
President
InterSociety Consortium for Plant Protection

I am here this morning by virtue of my position as chairman of the Executive Council of the InterSociety Consortium for Plant Protection (ISCPP). The Consortium is made up of representatives from the four main U.S. plant protection societies: Entomological Society of America, American Phytopathological Society, Society of Nematologists, and Weed Science Society of America. Each of these societies is represented on the Executive Council by their Vice-President (or President-elect), President, and immediate past President. The Executive Council of the ISCPP meets two or three times each year in Washington, D.C. One of our objectives is to "provide sound scientific advice to organizations and agencies concerned with establishing policies, regulations and improved methods for plant protection." And this is our role, our involvement, in organizing this Imported Fire Ant Symposium.

The subject matter of the panels has been selected with the intention of covering all aspects of the IFA problem. Dr. Fred Tschirley, symposium coordinator, will go into detail with you about the topics assigned to each panel, and how the symposium is to proceed. What I wish to emphasize now is that many of the panel members, who are also members of one or more ISCPP constituent societies, are here as agricultural research scientists. You can expect to hear from them what they believe to be the latest facts about the fire ant.

However, there are two caveats you should be aware of: the first is that a given set of scientific facts can be used to support divergent conclusions by twisting, distortion, or selected emphasis of these facts. The second is that what seems to be scientifically true today may no longer seem to be true at some future time because of new evidence or better interpretation of existing data.

What this symposium is striving for is an unbiased presentation of the scientific facts, as we now perceive them. These facts can then be used to determine what additional information is needed to solve the fire ant problem on a long-term basis. And this will probably require a lot of additional research to provide some very specific bits of information. A more immediate goal of this symposium is to provide decision makers with the information necessary to deal with the IFA on a daily basis until a holistic approach to control this pest can be developed.

OPENING REMARKS

John A. Todhunter
Environmental Protection Agency

It's a pleasure to be here with you in Atlanta this morning. I must confess, though, that not being from this region, I was reminded of the story of the Yankee fisherman who, fancying himself the complete angler, journeyed south of the Mason-Dixon to test his skills in your lakes and rivers. He had for a guide a Senior Southern Gentleman named Homer who knew better than anyone what was biting and where. After a few outings and major successes, our Yankee angler, not crediting Homer with contributing to any of his success, struck off for a stream that Homer knew had no fish. The Yankee cast out into the current which quickly took his line downstream. The angler began to reel in and met resistance. Quickly he pulled to set the hook and cried out to Homer "I got it, I got it! And Lord is it strong!" Well, old Homer stepped out into the stream and saw that the line was snagged around a submerged boulder that had been there since the Ice Age. Homer yelled, "You got it, all right," to the Yankee fisherman. "You got old Dixie and a helluva git you got!"

I guess that story has several morals, but the one I had in mind is the one that teaches us that for all our experience and expertise, we can still learn more. That is why I congratulate Charles Jeter, John Ferris, Harry Mussman, Walt Tschinkel, Reagan Brown, Carolyn Carr, Fred Tschirley and all of you for making this symposium on the imported fire ant a reality.

The imported fire ant, as Jim Buck Ross once observed, is just what it is: imported--the black ant variety from Uruguay, and the red ant from Brazil. They have been around since the twenties and thirties, and by the fifties they began to move beyond their point of entry around Mobile to nine southern states and Puerto Rico. The fire ant, imported or not, has become a major problem for the people of the South. Over 230 million acres are now infested. Their sting has been felt by humans and livestock in the thousands. Millions of dollars in crop losses, medical expenses and in means to combat them have been incurred.

With apologies to Pogo, we have met the enemy and this time, they aren't us. So why this symposium? You may recall that last February, I announced that EPA and USDA would sponsor a Symposium on the Imported Fire Ant. This decision was prompted by the State of Mississippi's application for conditional registration of the insecticide

Ferriamicide. It became clear to me at that time that we could not evaluate the Ferriamicide application in isolation from all of the many issues that surround the control of the fire ant. What we needed then and need now is information. And we expect we will receive that information from the participants of this Symposium. In essence, what we have today assembled is a multi-disciplinary task force of experts. Their task, over the next four days, is to examine the fire ant and the best possible method to rid ourselves of its harmful effects.

This is no simple charge, as we are all aware. Because there is no simple, risk-free solution to this problem that we know of. But try we must. Because our efforts here will affect the decisions of the EPA and USDA in this matter.

As you begin your deliberations, I ask you to consider a number of things. First, keep in mind that FIFRA is a risk benefit statute not a zero-risk statute.

Second, remember that regulatory decisions in the final analysis are subjective. There are a number of considerations that affect them—not the least is the level of risk that our citizenry is willing to accept.

Third, consider the impact of science on the regulatory process. Simply put, it is not possible to make a good regulatory decision that is based on bad science.

I am not asking you for unanimity, I know better than that.

What I am asking you for is your best scientific effort, leaving behind partisanship and past disagreements. Because what we produce by way of information at this Symposium will not only play a powerful role in the decisions of EPA and the USDA, but will affect for many years to come the environment of the South and the lives of its inhabitants.

I wish to thank you all for your participation and anticipate your guidance in this matter.

INTRODUCTION BY THE ANIMAL AND PLANT HEALTH INSPECTION SERVICE, CO-SPONSOR OF THE SYMPOSIUM ON THE IMPORTED FIRE ANT

James O. Lee
Associate Administrator
USDA, APHIS

Good morning! We are pleased to be co-sponsoring the Symposium on the Imported Fire Ant here in Atlanta this week. Dr. Mussman sends his regrets for being unable to be with you today and sends his best wishes for the Symposium.

Two species of imported fire ants were brought to the United States about 40 to 60 years ago, and they have become a pest of agriculture, a health hazard, and a nuisance to those persons in infested areas. The U.S. Department of Agriculture (USDA), Animal and Plant Health Inspection Service (APHIS), and Plant Protection and Quarantine (PPQ), are responsible for program actions designed to locate the ants through survey activities, to prevent or retard long distance spread through the application of regulatory procedures, and to reduce populations by applying control treatments, methods development, and environmental monitoring.

The imported fire ant can cause economic losses to agricultural lands as well as nuisance and health effects to humans. Agricultural economic losses due to fire ant damage are based on surveys and from extrapolation of data. The agricultural losses attributable to the imported fire ant have been documented for most of the affected states. In Florida, Georgia, and North Carolina, losses due to reduced efficiency of mechanical reaping of soybeans and damage to equipment have been reported. Estimates of losses ranged from $2.43 to $4.70 per acre, when the yield of infested fields was compared with that of uninfested fields. Reports of other crop damage include destruction of corn in Mississippi, Alabama, and Florida; okra in Florida; and peanuts and other crops in Alabama. In addition to the direct damage to plants and equipment, the presence of the imported fire ants in a field reduces worker productivity.

Individual adverse human health effects occur from the imported fire ant by: (1) causing discomfort, irritation, and the formation of a pustule at the site of the sting; (2) secondary infections that may occur at the site of the pustule and that may lead to gangrene and subsequent amputation of the affected appendage; (3) mortality in certain hypersensitive individuals; and (4) limiting normal work and recreational activities in heavily infested areas. Individual responses to stings range from very mild localized reactions of redness and tiny pustule formations, to severe systemic reactions that require hospitalization and medical treatment. These responses depend on the initial sensitivity of the individual to imported fire ant venom and to increased sensitivity that may develop as a result of multiple sting episodes.

Several sets of alternatives for control of the imported fire ant have been considered, including alternative control agents, alternative methods of application, administrative alternatives, and alternative funding sources. The control of imported fire ants may be achieved by the use of chemicals, by biological means, or by other methods. To date, greatest emphasis has been placed on the development and testing of chemical control insecticides. Chemical toxicants may be classified as: (1) proven agents, the use of which have been restricted or banned; and (2) new agents that have not been applied on a large scale. Unfortunately, there is no in-between at the present time.

The imported fire ant control program may be administered in several alternative ways: a federal program, a joint federal/state initiative, or independent state programs. A program administered exclusively by federal agencies is thought to be undesirable. On the other hand, a series of independent state programs would probably not yield optimum results. State boundaries are man-made and are not recognized by the imported fire ant. The optimum administrative approach therefore would be a federal program involving state governments and agencies. In this way, the wishes of individual states may be respected while the resources of all are pooled to formulate a cohesive overall control program.

The statutory authorities vested in the U.S. Department of Agriculture pertaining to program actions concerning the imported fire ant include the following:

- Organic Act of the Department of Agriculture, September 21, 1944, as amended (Title 7, USC, section 147a);
- Plant Quarantine Act of August 20, 1912, as amended (Title 7, USC, sections 151-165, 167); and
- Federal Plant Pest Act of May 23, 1957, as amended (Title 7, USC, sections 150aa-150JJ).

The imported fire ant control program may be funded by the federal government, state governments, or private citizens (farmers and householders). Historically, funding of programs has been shared between states and the federal government.

Based on an analysis of alternatives, the preferred alternative for control of the imported fire ant is one that uses an available and environmentally safe material applied by an effective yet comparatively inexpensive method. The aim of the cooperative imported fire ant program is to locate infestations of imported fire ants through visual surveys, to retard the spread of imported fire ants by regulating specified articles that are known to present a risk of spread, to reduce the likelihood of other areas becoming infested, and to control the ant population in areas already infested.

Remaining issues and concerns identified are: concern for human health and well-being resulting from increasing ant populations, that agency program actions should have total eradication of imported fire ants as the objective rather than control, restrictions on the use of pesticides to their fullest potential reduces the likelihood of complete control, a need for continued federal/state cooperative imported fire ant program, concern for the environmental effects of using a pesticide, and concern about long-term effects of using an insecticide that has not been fully tested.

USDA/APHIS continues to have a great concern for the impact of the imported fire ant. The future of any operational control program remains in the hands of all of us. Thank you for your time and good luck for the rest of the week.

HISTORY AND BIOLOGY OF FIRE ANTS

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In the time available, it is not possible to summarize fire ant biology in detail, and even if it were, such detail would probably defeat the purpose of this keynote address. Instead, I have chosen to make a more conceptual interpretation of the available facts about fire ants and to use these facts to paint a general picture of the biological nature and function of fire ants. The interpretation is not an exclusive one, even starting from the facts available. Considering the number and size of our gaps of knowledge, the future may very well see changes of interpretation.

The facts upon which I base my talk are the results of the work of many people over more than three decades. Complete attribution is impossible in such a short review, and to those who feel inadequately cited, I apologize.

Because there are many non-biologists in the audience, let me begin with a brief description of the individual and colony life cycles. Fire ants belong to the insect order Hymenoptera, which also includes the bees and wasps. As a result, the three groups share most of the major life cycle characteristics. Most importantly, fire ants, like other Hymenoptera, are holometabolous; that is, they develop through a complete metamorphosis. The individual begins life as an egg, which hatches into a legless, grublike larval stage. The larva is a stage specialized for feeding and growing, and almost all growth occurs during this period. As in all insects, growth is accomplished by periodic molting, or shedding of the cuticle (skin). Having reached its final size, the larva undergoes a metamorphic molt and becomes a pupa in which various adult structures, such as legs and possibly wings, become apparent for the first time. The pupal stage is transitional between the larva and the adult that emerges during the final molt. In insects in general, the adult stage is specialized for reproduction and dispersal, but with ants only some adult individuals are capable of reproduction (queens and males), the remainder are a sterile worker caste. In all hymenopteran societies, all socially functional individuals are genetically female, with males serving only to inseminate females on mating flights.

The social unit of fire ants is the colony, and colonies, like individuals, pass through a characteristic life cycle with phases analogous to birth, growth, reproduction, and death. Fire ants are very typical of ants in general with regard to their life cycle. Briefly, it is as follows. In addition to workers and a queen, mature colonies contain winged males and females capable of flight and reproduction. These are termed variously the alates, sexuals, or reproductives. On a warm day following a rainy day, the workers open holes in the nest through which the alates exit on the mating flight. Mating takes place 300 to 800 feet in the air. Mated females descend to the ground, break off their wings and proceed to search for a place to dig the founding nest. In this founding nest, a vertical tunnel 2 to 5 inches deep, they seal themselves in order to rear their first brood of workers. They do this entirely without feeding by utilizing reserves stored in their bodies in the form of fat bodies, wing muscles, and food stored in the crop. The first worker brood takes about a month to develop and are the smallest individuals (minims) in the entire colony cycle. They open the nest, begin to forage for food, rear more workers, and care for the queen. Hereafter, the queen essentially becomes an egg-laying machine.

The colony grows rapidly by the production of workers who gradually enlarge the original vertical tunnel into multiple passages and chambers and eventually into the familiar large mound of spongelike, convoluted passages. Colony maturity is attained when sexuals are once again produced. When these sexuals leave on mating flights, the colony cycle is closed. Mature colonies of fire ants consist of an average of about 60,000 workers, weighing 70 to 80 grams, but colonies of up to 150,000 or more have been reported.

In 1972, Buren recognized that what was previously considered a single species of fire ant actually consisted of two species, both introduced to the USA from South America. The first was *Solenopsis richteri* Forel and, the second was an undescribed species, which Buren, with characteristic whimsy, named *Solenopsis invicta* Buren. This second ant is greatly predominant and has been given the unfortunate common name of the red imported fire ant. Logic would require that, in its homeland in Brazil, this ant would have to be called the "exported fire ant." I suggest that we not defeat Linnaeus and his wonderful Latin binomial system. Let us call it simply the fire ant, *S. invicta*.

Solenopsis invicta is at home in an extensive, seasonally flooded plain forming the headwaters of two rivers in southern Brazil, an area called the Pantanal. *Solenopsis richteri* is at home in Uruguay, parts of Argentina, and Brazil (Fig. 1). Both were introduced to the United States by unknown means at Mobile, Alabama. *Solenopsis richteri* was first recorded in 1918 and spread slowly northward into Mississippi and Alabama. Sometime between 1933 and 1945, perhaps around 1940, *S. invicta* appeared in the Mobile harbor area and proceeded to spread more rapidly, displacing *S. richteri* from most of its range. Spread of both species was both by natural mating flights and man-aided through the transport of nursery stock. Thus, by 1953, the range of the fire ants (remember the two species

Fig. 1. The ranges of *Solenopsis invicta* and *S. richteri* in South America. Darker shading is estimated range of *S. richteri* in 1974, the dotted line is a more recent assessment of the actual range by Buren (pers. comm.). *S. invicta* range in light shading (from Buren et al. 1974. J. N.Y. Entomol. Soc. 82:113-124).

were not yet distinguished in these early reports) consisted of a continuous area from the Gulf coast to central Alabama and Mississippi and a large number of incipient populations associated with nurseries throughout the Southeast (Fig. 2). Appearance of such incipient populations ceased after the fire ant quarantine of 1956 was imposed. By the mid-70's, these incipient populations had coalesced, and the fire ants occupied most of the warmer parts of the Southeast as far west as Texas and as far south as Corpus Christi (Fig. 3). Most of this range is that of *S. invicta*, *S. richteri* being presently restricted to parts of northern Mississippi and Alabama.

There has been much speculation on future spread and the ultimate range of fire ants. Climate is one of the primary limiting factors to the ranges of many insect species, and the study of Pimm and Bartell (1980) is interesting from this point of view. These authors studied the climatic characteristics of the areas into which the fire ant, *S. invicta*, spread between 1965 and 1976. They created composite climatic variables describing a region's temperature (Factor 1) and wetness (Factor 2). From Fig. 4, it can be seen that during this period the fire ant spread mainly into climatic zones that were warmer and drier, mostly in Texas. There was some small spread into warmer, wetter regions, implying that northward spread has reached its limit. Finally, there is no occupation at all of regions that are cold and dry.

There is other evidence that the northern range limit has been reached. Morrill (1977) reports great winter kill of fire ant colonies in piedmont Georgia during the winter of 1976-77. Colonies in unprotected locations suffered 94% mortality in piedmont Georgia, while comparable colonies in southern Georgia showed only 20% mortality. Clearly, winter harshness must be more and more limiting to fire ant populations as they proceed northward. The period for successful colony establishment also becomes shorter as one proceeds north, further limiting northward spread. All evidence thus indicates that *S. invicta* will not spread significantly further north.

On the other hand, some continued westward spread seems to be occurring, but its limits are not yet clear. Pimm and Bartell suggest that parts of Texas will eventually be occupied but that the ant will not proceed north of the $0^{o}F$ isoline. A number of people have suggested that the ant could spread all the way across the Southwest to California and the West Coast, but these judgements are based almost exclusively on temperature and sometimes the total rainfall characteristics of these areas. An as yet undiscussed factor is the necessity of summer rains for fire ant reproduction. Mating flights normally occur only on warm days after rain, the rain being necessary not only to trigger mating flights but to ensure successful excavation of the founding nest

Fig. 2. The range of *S. invicta* and *S. richteri* in the USA in 1953. The two species were not yet distinguished at this time. The broken circles represent secondary populations, mostly centered at and limited to commercial nurseries (from Wilson, E. O., and W. L. Brown. 1958. Evolution 12:211-218).

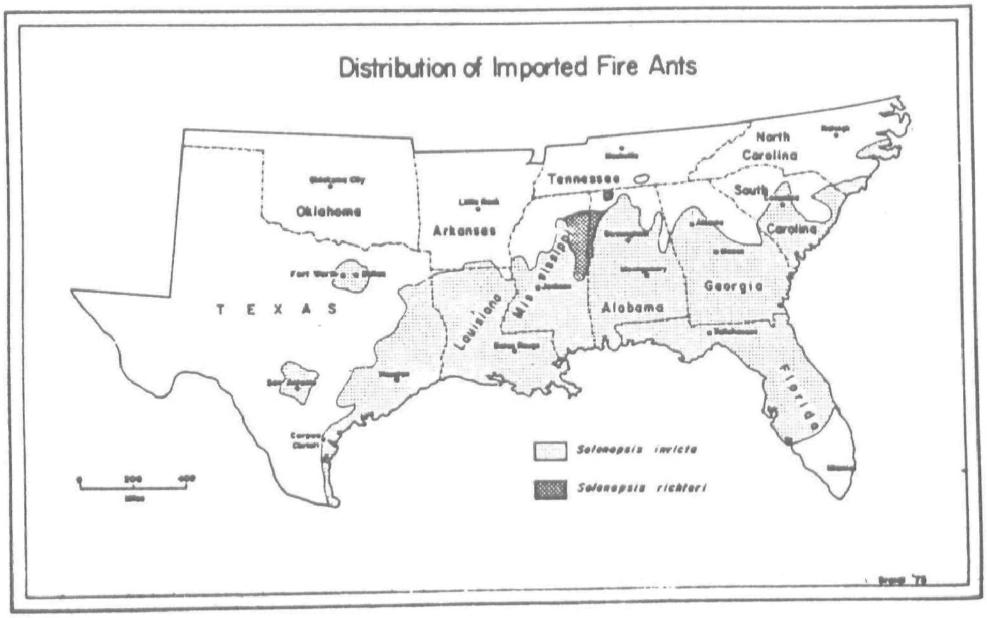

Fig. 3. The ranges of *S. invicta* and *S. richteri* in the USA in 1974. *Solenopsis richteri* is represented by the darker shading (from Buren et al. 1974. J. N.Y. Entomol. Soc. 82:113-124).

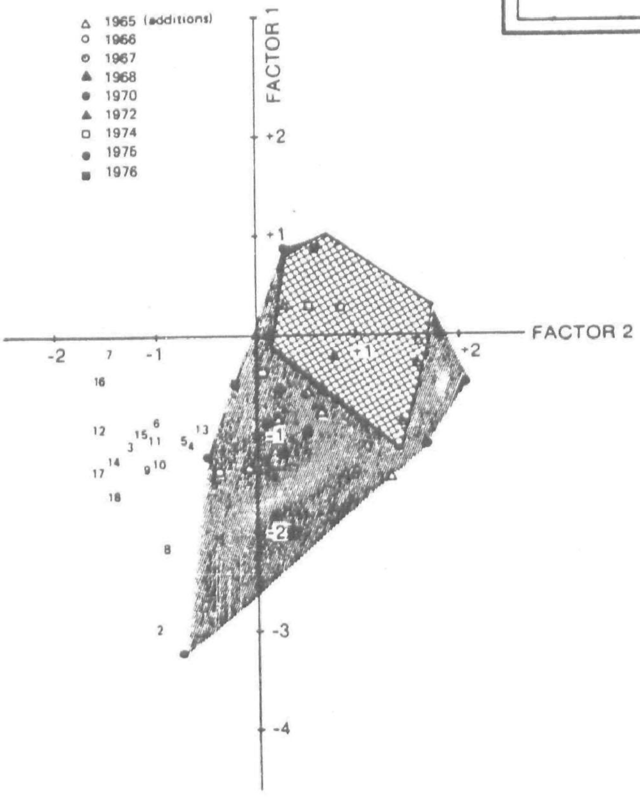

Fig. 4. The "climate space" occupied by *S. invicta* in 1965 (cross-hatched) and 1976 (shaded). Factor 1 is a composite climatic variable representing temperature, and Factor 2 wetness. The numbers represent counties in Texas into which the ant will probably spread (from Pimm, S. L., and D. P. Bartell). 1980. Environ. Entomol. 9:653-659).

and survival through the founding period. No study has yet considered the timing of rain as a possible range-limiting factor. How frequent must warm rain be for maintenance and spread of populations? Can the fire ant reproduce in regions such as California that get almost exclusively cold winter rains, followed by rainless summers? A careful study of such factors will probably show that the potential range of *S. invicta* is considerably less than many have suggested.

All studies of future range have dwelt almost exclusively on abiotic factors. Biotic factors limiting spread are almost totally arcane. As the ant spreads toward subtropical Texas and Mexico, it encounters an ever richer ant fauna, possibly containing components with habits similar to its own. How will such interactions with other ants, or for that matter, any other biotic community, influence its success in these regions? There are essentially no data.

Overall then, we can summarize range information by concluding that the ant has reached its nothern range-limit and is still spreading westward. The ultimate western and southern range-limits cannot yet be predicted because we lack so much biotic and abiotic information.

ECOLOGICAL NATURE

Let us turn now to the ecological nature of *S. invicta*. I want to develop the case here that *S. invicta*, ecologically speaking, is a weed species, and as such, shows many of the biological properties of weeds in general. Weeds are animal or plant species that are adapted for the opportunistic exploitation of ecologically disturbed habitats. Naturally, these are created by flood, fire, and storm, and consist of new sandbanks, slumps and landslides, burns, and windfalls. Man however, creates vast stretches of such disturbed habitat by clearing forests for agriculture, domestic, and other uses. The plant and animal communities that occupy such disturbed habitats are called early secondary or early succession communities, because, left alone, all such areas will gradually revert to the dominant climax communities, mostly deciduous forest in the Southeast. Because such early succession communities are ephemeral, and because they are, to a large degree, underexploited and understocked, the weed species utilizing these habitats are adapted for very rapid, scramble-type of exploitation with an emphasis on high reproductive rates and efficient dispersal rather than competition with other members of the community.

Let me discuss each of the weed-like properties of the fire ant in turn. First, the fire ant is clearly and dramatically associated with ecologically disturbed habitat, most of it created by man. Thus, *S. invicta* is abundant in old fields, pastures, lawns, roadsides, and any other open, sunny habitat. It shares these habitats with many other weedy plant and animal species, from human crops to lawn and pasture grasses, goldenrods, and dog-fennel. Humans are the fire ant's greatest friend, even though the sentiment may not be returned.

On the other hand, the fire ant is absent or rare in late succession or climax communities such as mature deciduous or pine forest. When it is found in these communities, it is usually associated with local disturbance such as windfalls and roads.

Although the fire ant's need for open sun has often been suggested as the primary cause of this pattern of occurrence, in reality this is only one of many correlated factors, and we must admit to having almost no hard knowledge of the biotic and abiotic causes of its distribution. Suffice it to say, *S. invicta*, like other weeds, is associated with open, disturbed habitats.

A second weedy property is the high reproductive rate that has evolved in response to the spotty, rather unpredictable and ephemeral availability of suitable habitat (in the absence of man-made disturbance). Success in such a situation goes to the animals and plants that "git thar the fustest with the mostest," with little attention paid to competition within the community. Fire ants, like other weeds, achieve a high reproductive rate in part by very high investment of resources in reproductives. From the meager data available, I estimate that *S. invicta* allocates 30 to 40% of its annual production in sexuals. This is quite similar to the allocation to seeds found in weedy species of goldenrod, and much higher than non-weedy goldenrods adapted for competition in late-succession communities (Fig. 5). Thus, the average fire ant colony in north Florida produces about 4,500 sexuals per year. Although very little information is available for comparison, this seems quite on the high side for ants in general and is almost certainly an adaptation to its weedy habits.

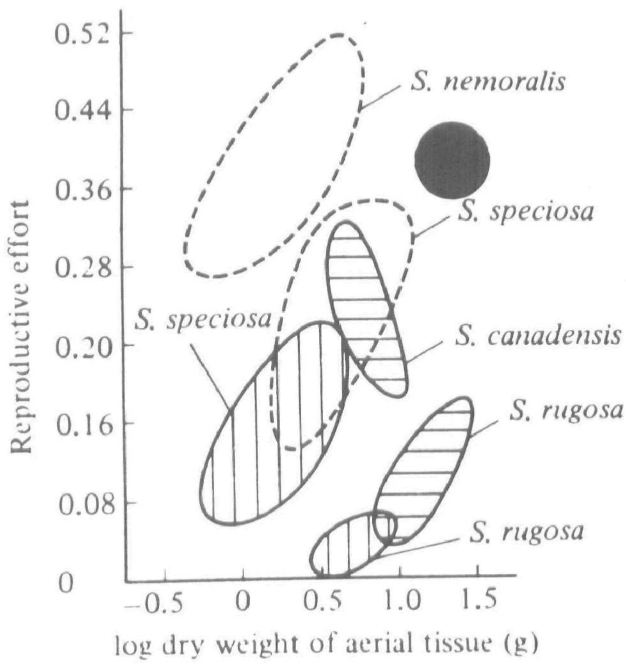

Fig. 5. Reproductive effort (proportion of production invested in seeds or sexuals) in relation to size of organism for goldenrods and fire ants (large black circle). Each enclosed area is represented by the individuals of a single population on a dry site (enclosed in dotted curve), a wet site (with horizontal shading), or a hardwood site (vertical shading) (modified from Ito, Y. 1980. Comparative Ecology, Cambridge Univ. Press).

A third weedy property is effectiveness of dispersal and colonization. In the absence of man-made disturbance, secondary habitat is scattered and unpredictable. Its exploitation depends on the ability to scatter propagules (sexuals or seeds) over wide areas on the chance that a few will find their way to an appropriate site and colonize it. The fire ant achieves this end by producing a large number of dispersing sexuals, as already mentioned. The sexuals are released from the colonies to take part in high-altitude, dispersive mating flights occurring throughout a large portion of the year (Fig. 6). The queens often fly or are wind-carried 1/4 to 1/2 mile or more before settling to the ground, although most settle at shorter distances. Although data are mostly unavailable, my impression is that the newly mated queens settle preferentially in disturbed, partly vegetated habitats, effectively colonizing them.

The ecological disturbance on which fire ants depend may not need to be gross, but can be rather a specific disturbance of the ant community only. This phenomenon was first observed by Summerlin, Hung and Vinson (1977), who treated with mirex an ant community in which *S. invicta* was a minor component. The mirex killed almost all of the ground-nesting ants, but after recolonization, *S. invicta* and another weedy species, *Conomyrma insana*, had greatly increased dominance over all species (Fig. 7). Many of the native species did not reappear in the course of this study. Because the fire ant has such a great advantage over other ants in colonizing, removal of the native ants resulted in a community consisting mostly of fire ants and another weedy ant species.

These results were recently experimentally confirmed by Buren and Stimac (personal communication), who treated one set of plots with mirex, one with Amdro and left one untreated as a control. Plots treated with either insecticide showed a reduction in all ant species, but were recolonized to much higher levels and greater dominance by fire ants. Untreated plots showed either no change or decline in fire ants. Clearly, the specific ecological stress or disturbance of the ant community with insecticide allowed the fire ant to increase its size and dominance over native ants.

Buren et al. (in press) have provided a computer-simulation model of how this takeover might proceed. They reasoned that there are a limited number of sites available for ants in a habitat, and these sites can be occupied by fire ants or other ants. In a fully stocked habitat, an ant of any species can appear in an area only if a site becomes available through death of a resident colony or appearance of a new site. The probability that a particular species will

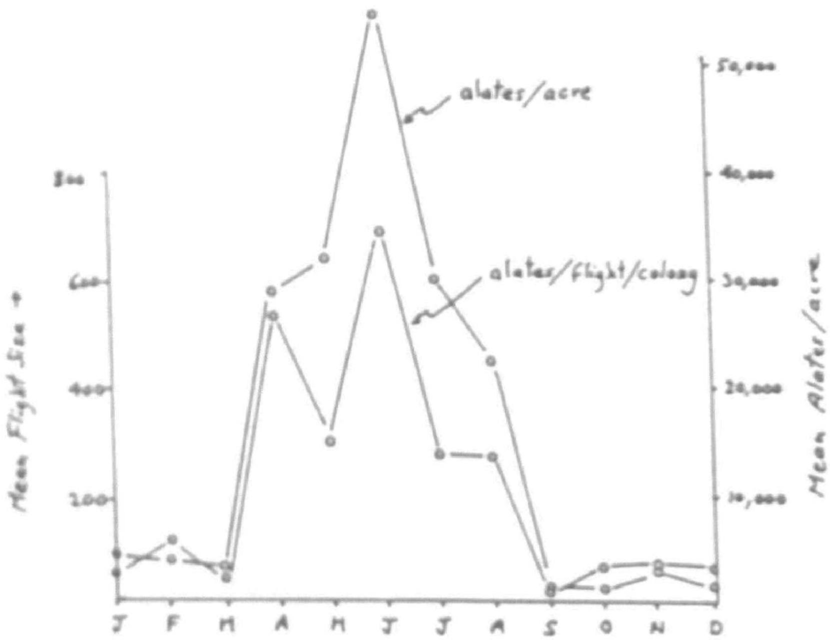

Fig. 6. Occurrence and size of mating flights throughout the year in N. Florida (from Morrill, W. L. 1974. Environ. Entomol. 3:265-271).

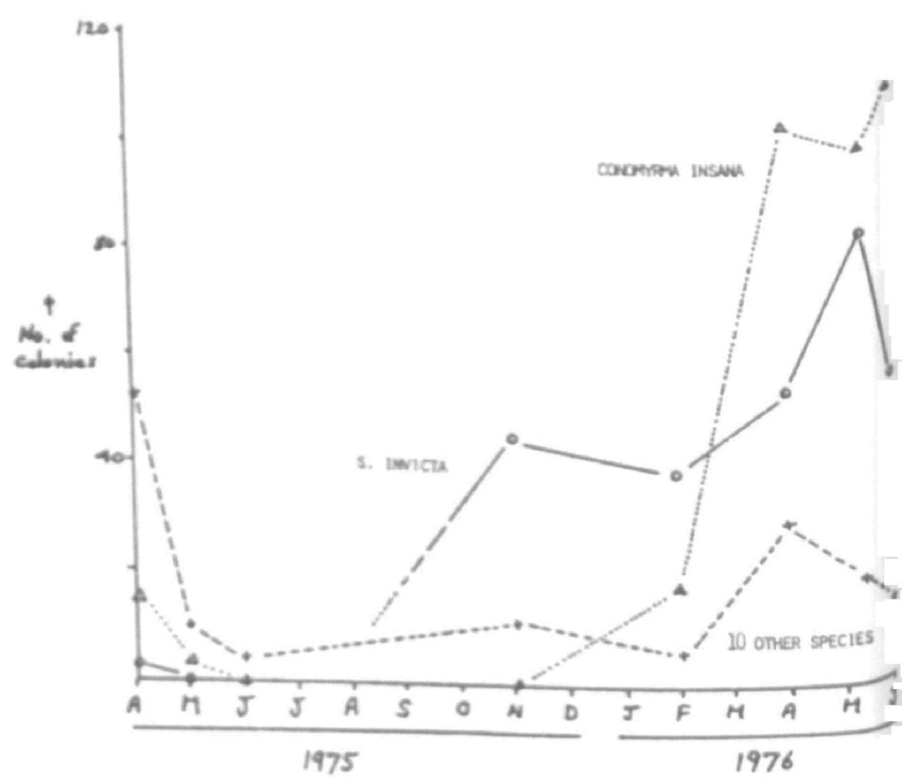

Fig. 7. Changes in an ant community after treatment with mirex. Ten other species are lumped together. The two weed species, *S. invicta* and *Conomyrma insana*, are shown separately (from Summerlin et al. 1977. Environ. Entomol. 6:193-197).

succeed in occupying an available site will depend upon its relative ability to colonize, an ability in which we know the fire ant holds a many-fold advantage over most native ants because of the large number of sexuals it produces. Because colonization by any species depends on the availability of sites, the rate at which sites become available, in combination with the colonizing advantage of the fire ant, will determine the rate at which the fire ant will increase its dominance in an area. Whether the sites are made available by natural colony mortality or by insecticide treatment is immaterial. Buren et al. showed that imposition of 95% annual mortality through insecticide treatment would cause a population consisting of 1% fire ants and 99% other ants to convert to one consisting of 99% fire ants and 1% other ants in only four or five years. Lower annual mortality rates lead to an exponential increase in the time it takes fire ants to reach the same level of dominance. Thus, simple as this model is, it explains the basic experimental findings of Buren and Stimac, and is supported by much biological information on fire ants.

The implications of these studies are clear: Large-scale, unspecific control programs such as those utilizing mirex or Amdro actually aid rather than hinder the establishment and spread of the fire ant and accentuate its dominance over native ants. The reversal of this dominance appears to be very slow and is poorly understood at present. Clearly, the relationship of the fire ant to other native ants in its community is an area of utmost importance about which we know very little. No program to manage fire ants can hope to succeed without such knowledge.

The fourth and fifth weedy properties of *S. invicta* are rapid growth and early reproduction. Fire ants achieve rapid growth by an emphasis on cooperation rather than competition during the founding and incipient colony period. Thus, a number of newly mated queens may share excavation of the founding nest and rearing of the first brood of minims. This cooperation, called pleometrosis, increases the chances of surviving the founding period and results in incipient colonies with about three times as many minim workers as colonies founded by a single queen (haplometrosis). Because of the nature of exponential growth, this initial boost is maintained throughout the early growth period, so that after 1/3 of a year, pleometrotically founded colonies are still three times as large as haplometrotic ones (Fig. 8), a clear advantage in competition and survival of winter or drought.

Once past the incipient period, colony growth is rapid, requiring about three years to reach upper colony size limits, and reproduction is early (Fig. 9). At the end of two

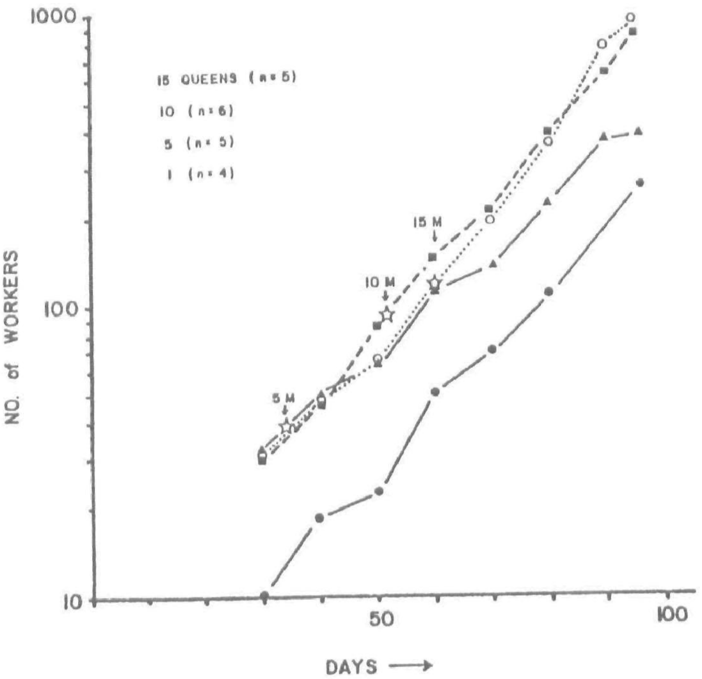

Fig. 8. Early growth in worker number of colonies founded by various numbers of queens. Pleometrotic colonies begin growth with about three times as many workers as haplometrotic ones and maintain this advantage throughout (Tschinkel, unpublished).

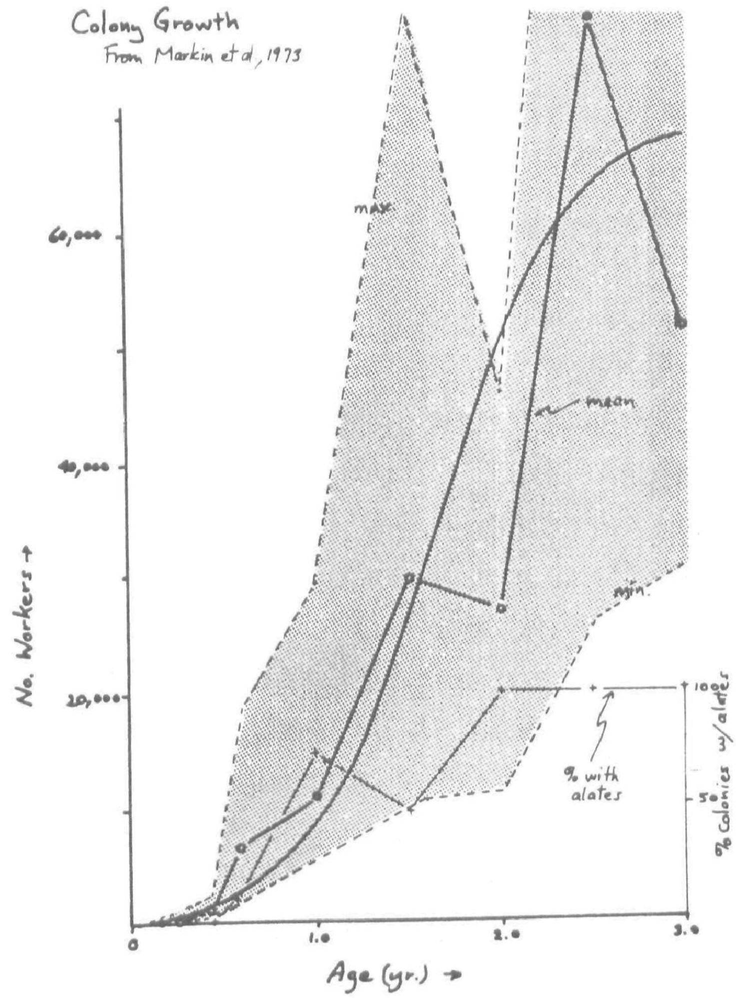

Fig. 9. Growth in colonies of *S. invicta*. Shaded area includes the extremes, line with points is the mean, and smooth curve is the best fitting logistic curve fitted to the mean data. The lower scale and graph shows the proportion of colonies producing alates (data from Markin et al. 1973. Ann. Entomol. Soc. Amer. 66:803-808).

years, 100% have done so. Such a reduction in the generation time has a great effect on increasing the rate of population increase.

In truth, we have only the most primitive understanding of the population dynamics within the colony during founding, growth, maturity, and senescence. Descriptive data are very crude and knowledge of mechanisms is almost entirely absent. At present, there is hardly even any speculation on how intracolonial population dynamics might be influenced by habitat differences, information of obvious importance to any management program. This subject is one of the more obvious voids in our knowledge and desperately needs attention.

An interesting aspect of fire ant colonies as they grow is that they change from being rather poor competitors, in fact from co-operators, to being rather good competitors. The most obvious aspect of this change is that colonies become territorial as they grow. That is, they defend a plot of ground against all other fire ant colonies, and possibly to some unknown extent against some other ant species as well. The size of these colony territories is proportional to the number of workers in the colony, and a consequence of territorial behavior is that fire ant populations reach an upper limit determined by the territory size of mature colonies. A typical figure for pasture land seems to be about 20 to 25 colonies per acre. Establishment of new fire ant colonies within territories occupied by mature colonies is probably impossible, for the resident workers kill newly mated queens that land in their territory.

A final, brief point concerning the ecological nature of the fire ant is its seasonality. *Solenopsis invicta* is a tropical ant lacking a true hibernation, yet it shows strong seasonality in many aspects of colony life. Most evidence indicates that this seasonality is probably imposed upon a basically unseasonal life cycle by seasonal fluctuations in temperature and, to some degree, rainfall. The influence of temperature on ecology and life cycle may be one more underappreciated factor in fire ant biology. We are accustomed to thinking of the effects of temperature on the rates of various processes, but there are ample hints for fire ants that temperature effects are often in the nature of thresholds or triggers. Examples of processes whose occurrence as well as rate is controlled by temperature would be worker brood production, alate brood production, mating flights, and successful colony founding. Such knowledge is of obvious importance to our understanding of the potential and realized ecological range of the fire ant.

Summing up the ecological nature of *S. invicta*, we conclude that it is an opportunistic, weed species depending on ecological disturbance for its continued existence and success.

COLONY FUNCTION

By colony function, I mean simply the general internal workings and social relationships within the colony, including behavioral, physiological, and morphological aspects. A useful organizing principle for my remarks is to consider colony life from the point of view of production. Organisms (and colonies) carry out the production of new biomass in such a way as to maximize reproductive success, this being merely a restatement of the principles of natural selection. Production of any kind requires some degree of control, as any factory owner knows, so let us look at colony function from the points of view of production and its control.

By production, I mean the obtainment of raw material in the form of food, water, and air and their conversion into new biomass. There are two primary localities for the production of new biomass in the colony: (1) the queen produces new biomass in the form of eggs. A queen in a large colony is capable of producing her own weight in eggs every 24 hours or less. (2) The larvae produce new biomass as they grow to become new individuals, either workers or sexuals. Under some conditions, colonies are capable of tripling their biomass (mainly workers) in a month.

Under the heading of control, I would place a variety of behavioral and physiological phenomena, many of which have received substantial research attention. As related to production, control deals with problems of the routing of materials (where does it go, and when?), rates of production (how fast?), and allocation of resources, including labor (how much to each subcomponent?).

A partial list of control mechanisms would include: (1) pheromones (chemical signals); (2) various behavioral interactions; (3) trophic relations (food flow and use); and (4) thermoregulation. This list is not complete, but will suffice for this general discussion.

Pheromones have received a good deal of attention and a number of effects have been attributed to pheromonal action. Because the queen is the only reproductive individual in the colony, there is widespread belief that she must also be the center of much of colony coordination. At least three biological characteristics of queens have been attributed to pheromones presumably secreted by her. The first and most obvious queen attribute is her attractiveness to her workers. In a normal colony, the queen is always mobbed by a dense retinue of workers who cluster around her, groom her, feed her, and whisk away any eggs she may lay. A number of workers (human) have shown that the attractiveness of the queen appears to be the result of a pheromone secreted by her and extractable from her body. More recently, Vandermeer and others (1980) have shown that the contents of the queen's poison sac are similarly attractive to workers, and it is possible, though not yet certain, that this is the same attractant described by earlier workers.

A second and third attribute of the queen is that her presence prevents winged female sexuals (alates) from breaking off their wings (de-alation) and undergoing ovarian development. Fletcher and Blum (1981) have recently presented evidence that both of these effects are caused by pheromones produced by the queen. Whether all three of these effects are caused by a single chemical compound or by several is, at present, unknown. If the fire ant parallels the honeybee, there are probably several pheromones with complex actions and interactions, and the unraveling of this chemical annd biological Gordian knot will occupy years to come.

A number of other pheromones also aid in colony control. Let me list them briefly, pointing out that many additional pheromones probably still await discovery. (1) Larvae and pupae are coated with a surface pheromone that causes workers to recognize them and presumably to respond appropriately to them by feeding them, grooming them, and transporting them to favorable locations within the nest. This chemical signal acts only upon contact, and its nature is not yet known. (2) Workers recognize dead ants by chemical signals that the latter emit, and respond by removing the dead from the nest. While this case stretches the definition of pheromones somewhat, the death signals are, at least in part, chemical and appear within an hour of death. (3) I have mentioned the territorial nature of fire ant colonies. Although little hard evidence has ever been advanced, it has long been believed that recognition of colony membership is mediated by a characteristic colony odor shared by all members of a colony and different from that of members of other colonies. (4) Recruitment of food and new nest-sites is mediated by a trail-pheromone produced in the Dufour's gland in the gaster of workers. In the early sixties, Wilson (1962) showed that a fire ant forager returning from a food find applies a pheromonal trail to the substrate using the sting. Nestmates follow this trail outward to find the food, and may in their turn reinforce the trail upon their own return to the nest. Each worker's contribution is both attractive and ephemeral, lasting perhaps 20 minutes or so, so that the relative rates of trail reinforcement and loss determine the level of pheromone in the trail, and this in turn determines how many workers are recruited to the food. This chemical recruitment system regulates the mass response of the colony to the food (or nest-site) and is capable of quite fine adjustments to varying quantity, quality and distance of food.

While on the subject of recruitment and foraging, I should mention that fire ant foragers do not generally sally forth directly from the nest. Rather, the entire territory is underlain by an anastamosing system of underground foraging tunnels. Recruitment probably actually takes place from the exits of these foraging tunnels throughout the foraging territory.

Behaviorally and morphologically, colony function is dominated by an intricate division of labor based upon caste (queen or worker) and worker size and age. The basic division of labor, as in all social insects, is that of reproduction—the queen lays all the eggs and the workers do all the work. Within the worker caste, however, labor is further subdivided on the basis of worker size and age (Fig. 10). In a mature colony, workers range in size such that the largest weigh about 10 times as much as the smallest. Colonies begin life with only small workers but as they grow, the proportion and size of larger workers gradually increases, and there is no indication that this trend ever stops. This phenonemon adds a developmental-time dimension to any discussion of division of labor by size that has heretofore not been recognized. In any case, several general differences in behavior are apparent between large and small workers—large workers carry and handle larger particles and brood, they are more likely to cut up insect prey, less likely to feed on liquid food, and less likely to function in brood and queen care.

Large workers live much longer than do small workers, but all workers pass through a series of changes in the labor they carry out as they grow older. These age-related changes are superimposed upon and modified by the division of labor by size already discussed. Early in their adult lives, work-

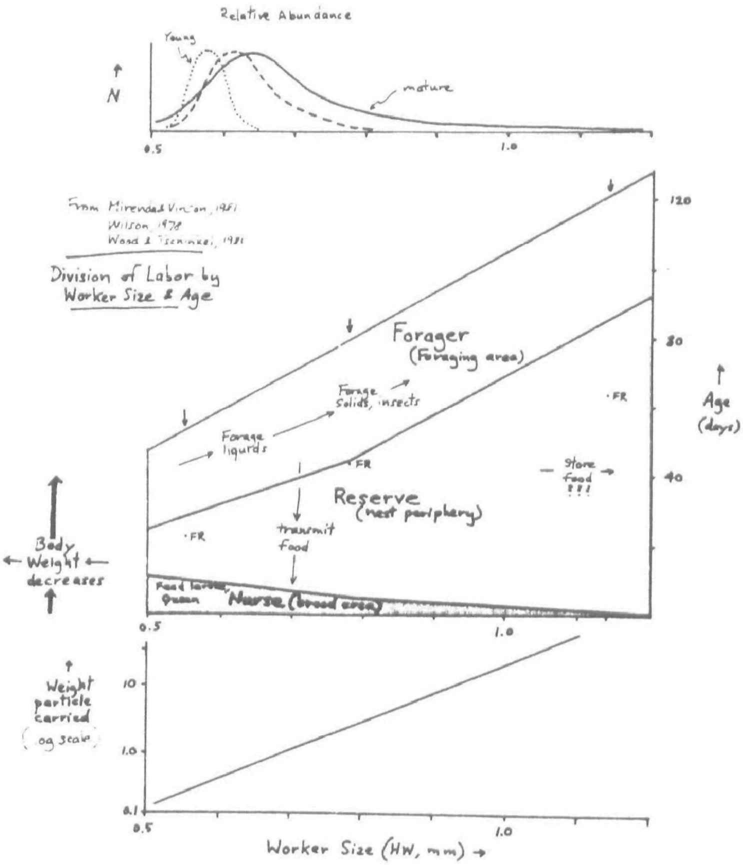

Fig. 10. Division of labor by worker size and age in *S. invicta*. Top: Size-frequency distribution of worker size in colonies during growth and maturity (after Wood and Tschinkel 1981. Insectes Soc. 28:117-128). Middle: Age, size, task, and location in nest. Age on vertical axis, size (head width) on horizontal axis (data from Miranda, J., and S. B. Vinson 1981. Anim. Behaviour 29: 410-420). Bottom: Size of particle carried by worker in relation to worker size. Note log scale (data from Wilson, E. O. 1978. J. Kansas Entom. Soc. 51:615-636).

ers act as nurses, taking care of the queen and brood, and are thus found mostly in the brood area. Small workers spend a larger proportion of their lives as nurses than do large workers, the largest essentially not functioning as nurses. As the workers age, they leave the brood area and move to the peripheral nest areas to take up their roles as reserves, for want of a better name. As such, they receive food from foragers returning to the nest, transfer it to the nurses, and take part in the many other nest functions such as construction, sanitation, defense, and others. During this period, large workers are more likely to store liquid food in their crops for longer periods than are small workers. Only during the last 25 to 40% of their lives do workers ever leave the nest to forage. During this final period, small workers are more likely to forage on liquids and larger workers on solids and insects.

It should be noted that none of these behavioral differences with age and size are sharp, and that there appears to be a good deal of flexibility of roles built into the system. We should also not forget that these patterns have been worked out for small colonies, and that there may be both quantitative and qualitative changes in them as the colony grows and ages.

Let's turn now to the flow of the food throughout the colony, the so-called trophic relationships. Most of the fire ant's natural diet is insects and other small invertebrates, although carrion, honeydew, and some plant material are also taken. Only about 10 to 20% of the colony acts as foragers at any given time, so that the food they collect must be shared with the other 80 to 90% of the colony. Workers themselves utilize only a small proportion of the colony's food, and what they do utilize is primarily carbohydrates and sugars. The bulk of utilization is by the two most important producers in the colony, the queen and the larvae, both of which get the lion's share of the protein as well. Once foragers have brought the food back to the nest, it enters a subtle complex web of exchanges, conversions, and processes (Fig. 11), that we are finally beginning to unravel, thanks to the work of such researchers as Howard, Sorenson, and others. Foragers pass the food to a group of younger workers called reserves, who in turn transport it from the nest periphery to the brood and queen area where they share it with the nurse workers. Nurses are the youngest class of workers, who carry out the functions of brood and queen care and hence are usually found in the brood area. Nurses probably convert some of the food to glandular secretions, and they pass both these and liquid food to the second and third stage larvae and to the queen, all of whom subsist entirely on a liquid diet. Solid food is

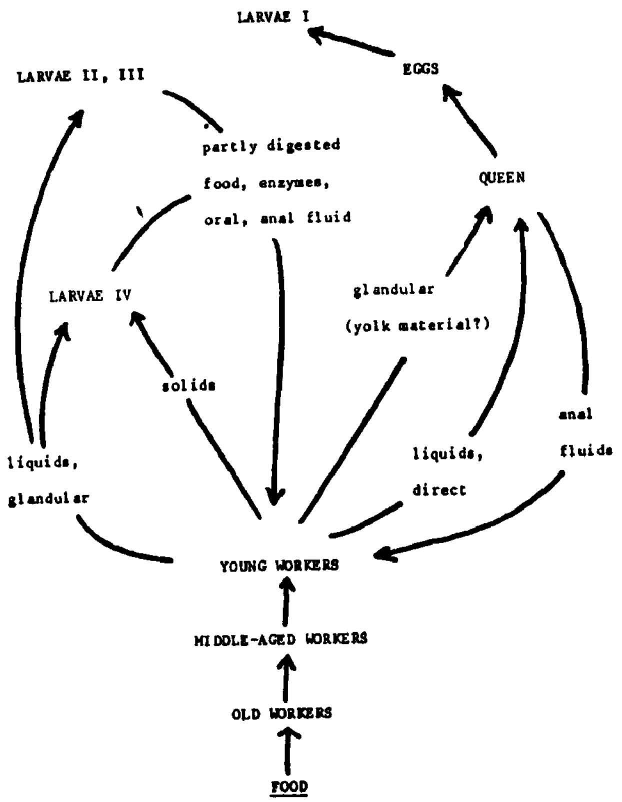

Fig. 11. Trophic relationships within colonies of *S. invicta*. Arrows indicate the direction of food flow.

passed to the fourth stage larvae, who process it, utilize part, and probably pass some of it back to the workers in partly digested form. They may also pass back glandular secretions of an unknown nature as well as excreted material. The queen may also pass back excreted or secreted material, but she obviously produces eggs from what she eats. Many of the eggs hatch, which is what eggs should do, but there is evidence that some may be eaten by the newly hatched, first-stage larvae, an added complexity in trophic relations. We have recently found that larvae are needed for continued egg-laying by the queen.

The image that is emerging with respect to the flow and use of food is that the various members of the colony are all pieces of a whole metabolic system where each plays a distinct metabolic behavioral role and all are interdependent. As yet, we have only a dim idea of how this metabolic labor is subdivided and specialized among colony members, but we know enough to see the beauty and sophistication of it.

IMPORTANT UNANSWERED QUESTIONS

There are many important unanswered questions concerning the biology of *S. invicta*, and their discussion could occupy whole conferences. Let me deal with a sampling of some questions I feel are important or interesting.

I. Certainly one of the largest holes in the fabric of our knowledge of fire ants is in the area of the population dynamics of colonies. In Fig. 12, I present a hypothetical survivorship curve based upon my impressions and very sketchy data. The curve incorporates the following characteristics: (a) very high mortality during the mating flight and colony founding period, with perhaps as little as 0.1% survival; (b) reduced but still substantial and steady colony mortality during the growth phase; and (c) rela-

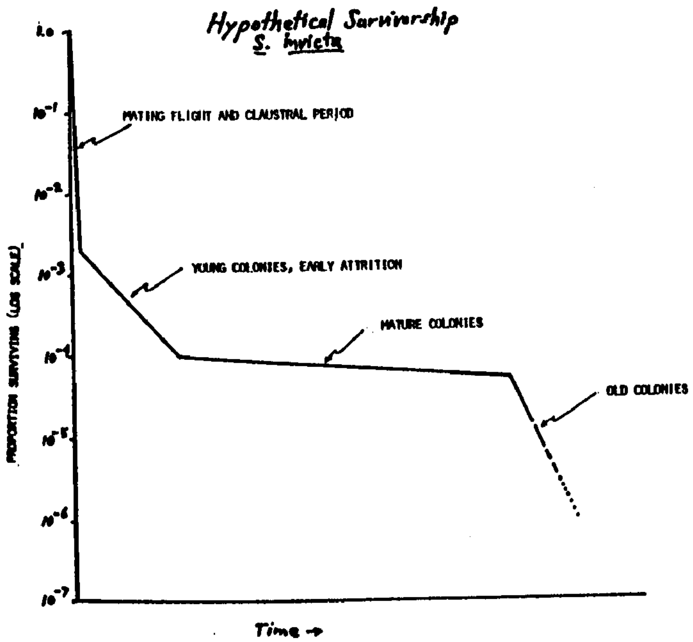

Fig. 12. Hypothetical survivorship curve for colonies of *S. invicta*. Note that the proportion surviving is on a log scale.

tively low mortality during the colony maturity stage. We have absolutely no idea of what happens to colonies when they get old, so I have entered this phase as a dotted line. Is there increased mortality during this period? While this survivorship curve may turn out to be more or less correct in its outlines, we have no quantitative data on age-specific mortality during any of the life cycle phases. This kind of "life-table" information is absolutely necessary for an ecological understanding of the fire ant, let alone a management program. Ultimately, if we are to manage it intelligently, we will need this kind of information for each of the different environments that the fire ant occupies.

II. The relationship to native ants has already been mentioned. Although an exotic, the fire ant is a member of a biological community, relating in some manner to other members of that community. I have already provided compelling evidence that its relation to other ants is a key component in our understanding of fire ant ecology, yet only scattered, generally unquantitative information is available.

III. While we know generally what fire ants eat, we have only poor quantitative knowledge of the impact of their feeding on the community in which they live. Furthermore, individual colonies show idiosyncratic food preferences whose meaning and origin we do not understand. Surely, this is an important aspect of any bait-based fire ant control method.

IV. The process of colonization of available habitat is poorly understood. How much control do queens exercise over the sites in which they settle after a mating flight? How are these sites selected? Which site and other physical characteristics influence success of colony foundation and how much? The founding period is obviously one of the most vulnerable stages of colony life, so that, from the management point of view, knowledge of this period seems imperative.

V. The number of mated queens during

various parts of the life cycle is emerging as an important question. I have mentioned that colonies are often founded by groups of mated queens in cooperation, and we have some dim idea of what might be the advantages of such behavior, though none are as yet quantitatively characterized. We know that, during the post-founding period, the workers kill all but one queen, so that the colony enters the growth phase with a single queen. It is therefore interesting that mature colonies often have more than one inseminated queen, capable, under the right conditions, of laying eggs. In most of the fire ant's range, these extra queens are inhibited from laying eggs, but can take the place of the colony queen-mother if she is lost or dies. In some of the western parts of its range, all of the mated queens in a colony may lay eggs (polygyny), and a colony may contain hundreds or even thousands of laying queens. What brought about this profound change, and why? What is the effect of queen number during various parts of the colony cycle on the ant's ecology, and possibly on its potential range? What is the source of these multiple mated queens? Are they adopted after mating flights? If so, why are they not killed? Does mating take place in the nest? If so, what is the genetic importance, and what effect does it have on the westward spread? If mating flights are unnecessary in polygynous colonies, can the ant survive in areas where there is no summer rain, such as California?

VI. Finally, the fact that, in comparison with those of Brazil, the fire ants in the USA are all much more closely related to one another because they are descended from a single pair or small number of individuals has received practically no attention. According to kinship selection theory and plain common sense, this situation could bring about major differences between the biology of the fire ant in the USA and its biology in Brazil. For example, it might affect the degree of cooperation and thus success during the founding period, it might affect the degree of colony distinctness and competition, and it might even affect the mode of reproduction.

SUMMARY AND FINAL REMARKS

In closing, the fire ant is a weed species whose continued existence is favored by human ecological meddling. Its success as a weed is based on high reproductive rate, excellent dispersal and colonizing ability, rapid colony growth, and early reproduction. What we do not know about its ecology can indeed hurt us, as is becoming clear with respect to large-scale, insecticide-based control programs. Colony life is dominated by a complex and subtle division of labor and an intricate set of trophic relationships. These and various behavioral control mechanisms regulate colony function to maximize reproductive success.

Seen from the biologist's point of view, without the rancor and heat characteristic of the political arena, the fire ant represents a wonderful research opportunity almost unique in the history of myremecology. The ant's abundance, ease of maintenance, and general habits make it an outstanding subject for research, while our society's relatively high need for knowledge of this ant gives us the opportunity to carry out this research. This potential knowledge may some day more than repay us for the real and imagined damage and aggravation the fire ant caused along the way.

Whatever we, as a society, decide to do about the fire ant, whether it be to fool with it or leave it alone, we are obligated to do it intelligently, with a sound foundation of biological knowledge. If the decision is to "do something" about the fire ant, even if only in certain situations, we must know a great deal more of the fire ant's secrets before we can ever hope for success.

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THE STATE PERSPECTIVE OF THE IMPORTED FIRE ANT

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For many years, the imported fire ant was considered a rural problem. It represented a headache for the farmer, rancher, and rural landowner, but was of little concern to urban residents, and therefore to urban legislators.

Today, the situation has changed dramatically. No longer are our urban parks and playgrounds free from this damaging and dangerous pest. The appearance of fire ant mounds on football fields, in city parks, and on urban lawns has brought into sharp focus the fact that the fire ant is a concern of all citizens.

The imported fire ant now totally infests several southern states, and threatens to overrun several others. Texas, Alabama, Arkansas, Florida, South Carolina, North Carolina, Mississippi, Louisiana, and Georgia all report infestations, and Puerto Rico has just recently been added to the list. In the south a total of 230 million acres are infested. In Texas alone, the fire ant now infests 45 to 50 million acres, and the number grows each day.

The fire ant is marching like Sherman's army throughout the South, and it is safe to say that the threat is no longer of infestation, but of invasion.

There is a very real need today to address the fire ant problem in a calm, rational manner, especially in light of the sensationalism surrounding the issue. This conference will do a great deal to fulfill this need. But the fact remains that the fire ant is one of the most damaging and insidious pests to come down the pike in a long while. Consider these facts:

1. Each month, two-and-a-half million Americans are stung by the imported fire ant. Some 4,000 of these victims experience allergic reactions. In Texas, two deaths have been officially attributed to fire ant stings. Deaths also have been reported in Georgia, Florida, Alabama, Mississippi, and North Carolina.

2. Productive farm and ranch land is being abandoned because of fire ant infestations. Infested counties in Texas average 80 to 90 mounds per acre. However, we have seen up to 600 mounds per acre in very severe cases. From a purely economic viewpoint, the question must be raised as to what effect this will have on property values in both rural and urban areas.

3. While the economic impact on stockraisers can be fairly easily determined, an unknown factor at the present time is the extent of damage to wildlife. Fire ants will viciously attack new born calves, but they

also will kill quail, ground squirrels, young deer, and even earthworms.

4. So far, the imported fire ant has not moved into the colder states, nor farther west than Texas. However, the fire ant is a notorious "hitchhiker." Every state is vulnerable as long as the possibility exists that the fire ant could accidentally be introduced through interstate movement of vehicles and products.

5. Preliminary studies show that fire ant infestations can definitely decrease yields in some crops. One study documents a 5.6 bushel-per-acre decline in soybean yields in infested fields. Yield damage also has been seen in corn crops. The spread of the fire ant into major citrus and vegetable producing areas of the nation—such as the Lower Rio Grande Valley of Texas, where much harvesting is done by hand—could present serious danger to workers who harvest these crops. A point could be reached at which it would not be possible for workers to even enter the fields.

6. Definitive economic impact studies have not been conducted recently. However, in 1977 it was estimated that the nine infested southern states suffered crop losses and pastureland damage of over $50 million. That amount is certainly greater today.

The magnitude of the fire ant infestation in the South is alarming. But equally worrisome is the speed at which this pest has spread. Texas, one of the most seriously affected southern states, offers a good example. In 1973, 57 of 254 counties in Texas reported fire ant infestations. By 1975, the number rose to 71, and by 1977 the total stood at 91. As of this month, the list includes 110 Texas counties, some in the western-most areas of the state. Several scientists at a recent meeting in Texas pointed out that control pesticides with long residual qualities, now banned, are still in the soil and are helping keep down insect populations. As these chemicals degrade, we could see even more rapid growth in populations of several damaging insects, including the fire ant.

The following reports from individual states give some indication of the scope of the problem:

From the Alabama Division of Plant Industry: At the present time, only three of Alabama's 67 counties remain free of the fire ant. The greatest number of complaints come from forage farmers, but calls also are received from nurserymen, homeowners, school officials, and others.

The Arkansas State Plant Board reports that population density has increased dramatically over the past two or three years as no control program has been in existence.

Every land acre in the state of Florida is infested with the imported fire ant, according to the director of the Florida Imported Fire Ant Program. He reports a sharp increase in the number of fire ant stings among workers in citrus groves, as well as damage to young citrus trees caused by ants girdling the trees.

Increases in fire ant populations on newly-developed apartment, condominium, and business sections has focused the problem in many of South Carolina's urban areas, according to state entomologists.

North Carolina reports a somewhat less severe infestation problem than most other southern states. Because of the limited problem, state entomologists report that they are in a position to successfully control the spread. Officials, however, underscore the continued need for a control material that is inexpensive, effective, and can be applied during most of the spring, summer, and fall months.

Mississippi reports that the ant is rapidly moving into northern portions of the state that formerly were fire ant free. State officials report serious problems caused by the fire ant undermining levees used for flood control. In addition, the number of pine seedlings destroyed by the ant is increasing.

In Louisiana, it has become necessary to cancel recesses at some schools due to fire ant infestations on playgrounds. Pest control officials report that since June of 1978, population density of the imported fire ant has increased by 75 percent.

Officials of the Georgia Department of Agriculture indicate that the fire ant, after being eradicated from much of the state with mirex, reappeared after the chemical was restricted, and its use banned.

In my own state, the House Select Committee on Fire Ants said, and I quote, "The problem has passed the serious level and reached the critical stage." The situation was deemed serious enough that the Governor this spring released an additional $500,000 in emergency contingency funds to fight the fire ant, an amount that was matched by the Texas Department of Agriculture's own contingency funds.

As you can see, the magnitude of the problem facing these southern states is immense. Most officials concede that the imported fire ant will never be eradicated in this country, but only controlled. Because of the threat to human lives and property, I cannot emphasize strongly enough the need for a nationwide mobilization to stave off this invasion. There is virtual across-the-board agreement that the following steps must be undertaken if we are to achieve the control that is so desperately needed:

1. The U.S. Environmental Protection Agency must make speedier decisions in granting experimental use permits for new control chemicals, so that effectiveness and environmental safety can be more rapidly determined for promising new control agents.

2. In many cases, state funding for fire ant research is nearly as great as federal funding levels, and we feel this is inequitable since the fire ant is a national problem. We must renew our commitment to discovering new biological controls, as well as

effective, safe chemical controls, and the federal government must bear a greater share of the load.

3. U.S. Department of Agriculture funding for fire ant control currently stands at $5.9 million, to be divided among nine states and one commonwealth. This amount could easily be utilized in Texas alone. Federal funding levels for fire ant control should be increased and maintained until effective control is achieved.

4. Two weeks ago, the Southern Legislative Conference of State Legislators approved a resolution urging each member to support the allocation of state funds for imported fire ant research and control. The resolution also supported several of the needed steps that I detailed previously. This action should serve as a model for legislators at the national level.

5. Perhaps most important, we must reach a national consensus among all concerned on how to best achieve the goal of fire ant control. This includes environmental groups, researchers, government agencies, and all others. Only through cooperation can this be achieved. Control of the imported fire ant is in the interest of, and not contrary to, environmental protection.

I hope that I have shed some light on the seriousness of this problem and of the difficulties facing those states that must deal with it. I feel this summit meeting is a giant step forward in the process of gaining the consensus and understanding that I mentioned, but it is only the beginning.

The situation damands action. Let us work together to make this conference a success and, ultimately, to achieve victory in the fight against the imported fire ant.

THE ENVIRONMENTAL PERSPECTIVE OF THE IMPORTED FIRE ANT

Carolyn Carr
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(Report not available at time of symposium completion)

Panel Reports

PANEL I

SOCIO-ECONOMIC FACTORS RELATING TO THE IFA AND ITS MANAGEMENT

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INTRODUCTION

It is important to evaluate the socio-economic aspects of the imported fire ant (IFA) to assure that the benefits and costs of alternative actions that could be taken toward the ant are considered. It is also important to consider the effects of the ant on people and their lives such as people's perception of the pest and the effects it may have on their health and happiness.

This report evaluates the benefits of controlling the ant, costs of large scale treatment programs, and the role of and need for education, information, and research in support of cost effective management of the IFA.

EVALUATION OF BENEFITS AND COSTS

Benefits of IFA Control on Agricultural Sites

Benefits from IFA treatment vary among different sites. Generally, the benefits of control on non-agricultural sites are higher than on agricultural sites. The data are not complete enough to support the assertion that the IFA is truly an economic pest in terms of agricultural losses. The IFA seems to be primarily a nuisance and human health pest rather than a pest that causes significant actual losses on large numbers of farms in the southeastern United States. IFA control in agriculture, however, can be beneficial in some situations. Areas that might benefit most from treatment are (1) livestock production sites, (2) hay production land, (3) soybeans, and (4) fruit, vegetable, and nursery crops. Studies report losses in hay yields, quality of hay, soybean yields, and damage to equipment from IFA. Other studies report livestock losses from IFA stings.

Studies by Lofgren and Adams (1981) showed an average decrease of 14.5% in soybean yields for eight paired fields with infestation rates of 49 to 176 mounds per ha. These losses are primarily due to harvesting difficulties caused by the ant. Lofgren and Adams are continuing these studies in an attempt to cover more of the infested area. At present one cannot generalize from these findings as to the significance of soybean losses across the infested area in the southeast U.S.

The IFA also causes discomfort and health problems to humans conducting agricultural activities. For example, ants tend to accumulate in hay bales left on the ground and create problems for workers cultivating and harvesting fruit and vegetables. Nursery workers also have problems. Additionally, nurseries that have IFA cannot ship plants to non-infested areas.

A detailed analysis was made of agricultural benefits and costs of IFA controls for one county in Florida covering the year 1973. The county has a broad range of agricultural and non-agricultural activities and a well-established IFA infestation. The analysis, completed as a Master's thesis in 1975 (James D. Wilson), indicated that treatment of 15,931 acres in Washington County, Florida, resulted in agricultural benefits totaling $2,128. Total operational and administrative costs for mirex treatment in the county were $11,947; for every dollar of agricultural benefits received, $5.61 were spent. The agricultural benefit averaged $0.13 per treated acre compared to the average treatment cost of $0.75 per acre for aerial applications. It is not known the extent to which these results can be extrapolated to other counties in Florida or the total nine-state area where the IFA is an agricultural pest.

In conclusion, given available data on agricultural losses and treatment costs, broad-scale control programs are not warranted. However, treatment may be justified where losses to crops or damage to machinery occurs and/or where IFA impair the effectiveness and safety of agricultural workers.

Health Effects of IFA and Its Control

IFA causes discomfort, a certain amount of serious reactions and infections, and a smaller number of deaths due to stings. Information on the size of the population and the characteristics of individuals at greatest risk from IFA is inadequate. To determine an economic rationale for IFA control, reliable estimates of the number of persons at risk due to sensitivity are needed.

The Florida study by Wilson (1975) included an analysis of non-agricultural benefits of IFA control. The analysis indicated that the probability of a household experiencing stings during a year was 0.76. The probability of a household experiencing stings and incurring professional medical costs was 0.048, and the probability of a household experiencing stings and incurring home medical costs was 0.734. Professional medical costs averaged $15.75, whereas home medical costs averaged $4.36. Another study (Triplett 1971) reported an average cost per person for professional medical care of $28.50. Wilson projected total home and professional medical costs in the county studied to be $9,154, with expected costs of $0.51 per household for professional medical care for stings and $2.40 for home medical care.

By far the most concern for human health associated with IFA is with hypersensitivity to stings. Rhoades et al. (1977) recorded allergy systematic reactions as reported to allergists in Jacksonville, Florida. They found an incidence rate of 3.8 per 100,000 population. Rhoades et al. (1977) believe that this is a minimal estimate since patients who went to emergency rooms and those who were not diagnosed were not counted. While the data on health effects, including secondary infections, is very episodal, it is clear that the health effects of the pests cannot be ignored.

Individuals who are allergic to the IFA toxins may incur considerable medical costs. These costs may include desensitization programs and/or hospitalization. There are also several well-documented cases of deaths resulting from IFA stings.

Further information on costs and benefits of control are available from large consumer surveys. In 1980 and 1981, the American Cyanamid Corporation conducted two large telephone surveys on the willingness of households to expend resources to obtain ant-free conditions. Approximately 82% of those who said they "had a fire ant problem" indicated they would treat the problem. Seventy-eight percent of those who would treat would do so with an insecticide. The surveys indicated that about one million households were treating for IFA with insecticides in 1981, with the balance (22%) using gasoline, boiling water, or a cultural practice. The areas treated by farmers were: lawns, 73%; gardens, 58%; pastures, 54%; row crops, 19%; and woods, 4%. The most frequently used insecticides were chlordane and diazinon. Seventy-five percent said they would pay at least $7.50 for complete control of up to one acre. The retail lawn and garden market price of Amdro® is $7.00 to $15.00 per pound.

There is considerable concern about possible short-term and long-term human health effects from insecticides used to control the IFA. The short-term problem centers on poisoning due to direct contact with the pesticides. In 1975, the EPA estimated approximately 200 deaths from pesticides in 1975 (EPA 1976). Work by Hayes and Vaughn (1977) suggests that about 50 were deaths in which accident could not be ruled out while the remainder were intentional, i.e., murder or suicide. Data do not permit estimates of deaths due to chronic disease induced by pesticides.

The possible long-term problems concern occupational exposure of some individuals and the risk to the general population from widespread use of IFA pesticides. The major pesticides (dieldrin, heptachlor, and mirex), formerly used for broadcast or aerial application in IFA control, have been cancelled due to possible human health and environmental risks. The compounds were found to be carcinogenic or teratogenic.

Little research data are presently available on possible health effects of the two pesticides now being considered for IFA control. Amdro, a new compound, is only conditionally registered. Ferriamicide, which is not registered, is a new formulation of mirex. While little is known about ferriamicide, mirex was cancelled because of its teratogenic and carcinogenic properties and because of the dangers posed by its degradates, which include kepone and photomirex.

EVALUATION OF ALTERNATIVE LARGE-SCALE TREATMENTS

The purpose of this section is to identify possible alternative large-scale IFA treatment programs or scenarios and to consider their costs and operational feasibilities. Decisions must be made about chemical registration for aerial and/or ground broadcast application. Also, decisions must be made on the extent of financial and institutional support for pesticide application programs, primarily large-scale aerial broadcast programs.

Tables 1 through 4 outline four alternative programs including approximate treatment acreages, treatment costs, and indications of operational feasibility and limitations. The particulars presented in these tables should not be taken as projections of actual outcomes, but rather as indicative of a possible range of outcomes. Key aspects in the design of the four sample programs are as follows:

A. Chemicals assumed to be registered for use[1] (aerial, ground broadcast, and mound-to-mound): Amdro and ferriamicide.

B. Level of involvement/support by state/federal government units: (1) state/-federal eradication, totally funded and supported by public funds; (2) federal/state/-local government support and funding of aerial suppression program, with cost sharing in line with traditional formulas; (3) federal/state subsidization of aerial relief program with landowners paying a significant share of treatment costs, e.g., 1/3 (for Amdro $1.66 of $5.00 per acre of $0.83 of $2.50 per acre for ferriamicide); and (4) free market treatment by landowners, where they incur all chemical and application costs. Government roles in research and educational/extension.

Each alternative assumes the availability of Amdro or ferriamicide for purchase by landowners in addition to whatever treatment would be provided by the publicly supported programs.

For the three state/federal alternatives, the cost per acre of broadcast treatment was estimated as:[2]

	Amdro	Ferriamicide
Pesticide	$2.65	$0.35
Application, guidance, overhead	$2.35	$2.15
	$5.00	$2.50

For the non-subsidized relief approach, costs per treated acre were estimated as:

	Amdro	Ferriamicide
Pesticide	$6.00	$1.25
Application, guidance, overhead	$1.00	$1.00
	$7.00	$2.25

Table 5 summarizes the evaluation and outlines the key aspects of the four approaches. The eradication and suppression alternatives are not considered prudent or advisable, as they would cost more than the benefits derived. Funds would be better utilized in other pursuits. The subsidized relief type program haspotential in line with the approach now being used in several states. Subsidy levels could be adjusted to influence the scope of the program desired and/or availability of matching funds. The non-subsidized market approach appears most feasible and would offer maximum opportunity to tailor treatment costs to user benefits.

Before any funds are committed, the merits of the alternative approaches must be compared to the other public programs with claims on federal funds. An evaluation of the merits of large-scale treatment programs relative to other non-IFA programs has not been made. Also, when considering alternative treatment programs, decision makers should be cognizant of the possibility of legal action being brought against the use of ferriamicide. Since ferriamicide is a formulation of mirex, environmental organizations will probably challenge any registration of ferriamicide, even registration under Section 18, emergency exemptions, since there may be no documented agricultural emergency.

Data for Estimating Benefits and Costs

The current data are limited in their usefulness to assess the costs and benefits of the IFA in agricultural crops, livestock, property, forestry, human health, recreation, and wildlife. Consequently, the benefits and costs of various IFA control options cannot be fully evaluated. The following information represents the types of data that should be developed to estimate the costs and benefits associated with the IFA.

A. Costs

1. Crop production
    - a) Extent and unit value of direct losses from IFA feeding by crop and level of infestation
    - b) Extent and unit value of crop abandonment as a result of mounds or incomplete harvesting by crop and level of infestation
    - c) Unit value of reduced efficiency of cultivation and harvesting, by crop and level of infestation, for equipment and labor, including cost of machine damage and repair, time to perform activities, wage rates, and quality of harvested product
2. Livestock production
    - a) Number and value of death losses by type of animal and level of infestation
    - b) Veterinary costs by type of ani-

mal, frequency of occurrence, and infestation level

c) Value of reduced rates of gain or level of milk production by type of animal, frequency of occurrence, and level of infestation

3. Forestry
   a) Extent and value of losses by tree type and level of infestation
   b) Extent and cost of replanting by tree type and level of infestation
   c) Increased labor costs of planting and harvesting by tree type, level of infestation, and frequency of occurrence
4. Human health
   a) Number of deaths from IFA stings
   b) Treatment costs resulting from IFA stings
   c) Days and value of work lost from IFA stings
   d) Proportion of the population with systemic sensitivity
5. Recreation and wildlife
   a) Extent and value of loss of visitor days by type of recreation and level of infestation
   b) Number and value of death losses by species of animal and level of infestation

B. Benefits
1. Extent and value of IFA as a predator by crop and infestation level: includes reduced management costs, decreased insecticide use and application costs, and reduced crop losses
2. Impact of IFA on beneficial insect populations and the resultant ability of beneficials to control economic pests by crop and infestation level
3. Extent and value of predation on nuisance and injurious pests to humans and wildlife

Data are also needed to evaluate the benefits and costs associated with alternative levels and methods of control programs. These information needs follow:

A. Information on the current situation: geographical distribution, sites affected, intensity of infestation, and effectiveness of current control practices
B. Identification and description of controls
C. Effectiveness of controls by type and level of infestation (include resurgence aspect of IFA)
D. Costs associated with controls:
   1. Direct private costs
   2. Direct public costs
   3. Indirect private and public costs associated with reduced predation, resurgence, human health, and environmental effects
E. Benefits associated with controls:
   1. Value of reduction in crop and livestock losses
   2. Reductions in crop and livestock pro-

duction costs

3. Value of reduction in human health effects
4. Value of reduction in adverse recreational and wildlife effects

When plans are developed to collect data for analytical purposes, consideration must be given to the quality of the information required, the length of time available to collect and analyze the data, and the cost of these activities. In the case of IFA control and the role of various governmental units, there are short and longer term needs. Decisions on pesticide registration for IFA control are short-term, while evaluation of the control programs is a long-term need.

Economic Effects of IFA Outside Infected Areas

The IFA is a mobile pest, and some fear it could spread to areas where conditions are suitable for establishment. For example, the climatic conditions in California are believed to be compatible with the IFA. Given the extensive irrigated production of fruits and vegetables in California, the IFA, if established, could significantly impact such labor-intensive crops. Where the danger of such an agricultural effect is coupled with the effect the IFA could have on people as a nuisance and health problem, the federal government has some responsibility. The appropriate federal role in this case would be operating a quarantine and inspection program to prevent the interstate spread of IFA.

There appear to be no significant national effects of the IFA on the price of farm products. Therefore, consumer expenditures for food and fiber probably are not influenced by the presence of IFA.

EDUCATION AND EXTENSION ACTIVITIES

Although several agencies and institutions have been involved with IFA information, more education is needed. There is (1) a lack of reliable information on homeowners' knowledge and perceptions about IFA control procedures, and (2) considerable misconception about effectiveness of various pesticides, human hazards from aerial applications, and health effects of IFA stings. If properly compiled and presented, the current information on the IFA can decrease the human health and agricultural problems caused by the IFA.

New residents to IFA-infested areas, young children, campers, and residents to newly IFA-infested areas are logical education candidates. Local television, newspaper articles, and "welcome wagon" associations are useful media. Information on how to avoid ants, how to control backyard mounds, and what to do if medical help is needed should be presented. IFA training could be given in schools together with training for other dangerous insects and plants.

Special care should be directed toward individuals who are hypersensitive to IFA stings. Information about various precautionary and medical actions needs to be made available through school nurses, 4-H clubs, etc. Consideration should be given to forming national information networks predicting likely victims of serious reactions to IFA stings.

IFA control recommendations in urban areas for individual homeowners need special attention. Methods of control, speed of action, rates per mound, and hazards of pesticides need explanation. A regular extension publication to be used regionally should be a top priority extension activity. Radio and television programs for children and parents of young children are needed. Automatic telephone messages for IFA information should be tried, also.

Information on IFA should accompany IFA bait when it is made available through state and local programs. The current Florida information sheet is a good example. The state departments of agriculture should attempt to increase IFA information through their weekly bulletins.

Schools, rights-of-way, parks, and other public places often are treated. Managers and users of these facilities should have special IFA training programs through university extension offices. Urban pest control information from extension seems limited in many IFA areas. Demonstration projects in urban areas would be useful. Others that should help with IFA training are state park, public health, and military officials.

As soon as more research is available concerning seedling damage and soybean harvest, the agricultural extension service can expand its IFA control recommendations to include crop land. This could be done by soil type, cropping system, and coincidence with adjacent IFA infestations. Methods to avoid IFA damages must be included, such as changing type of hay-handling equipment.

Information directed at farm workers also is needed. Fruit workers, hay harvesters, etc., and their employers can be shown how to avoid stings. Farmers need information on the effect of IFA stings on the availability and productivity of labor.

GENERAL CONCLUSIONS

Federally-supported programs aimed at eradication or preventing the spread of IFA have not been successful. The current data are not complete enough to support generalizations about the importance of IFA as an economic pest across the currently-infested, nine-state region. Therefore, due to uncertainty of success and the widespread economic need, a rationale for future large-scale control programs to eradicate or prevent the spread of IFA cannot be defended. Funding as well as legal and technical constraints work against commitment to such efforts. A more prudent course would seem to be to pursue smaller efforts to relieve the pressure of the pest in localities where it is most critical. Through the use of market alternatives, public and private land managers can decide to apply controls where benefits appear to justify the costs.

The appropriate role of government, especially federal, is to conduct research to provide pest management information, to operate inspection and quarantine programs, to attempt to protect areas not already infested, and to see that public-owned lands are managed properly with respect to IFA.

RECOMMENDATIONS

Federal funding

1. The imported status of the IFA should not be considered justification for further federal involvement in control or eradication programs. However, federal support of and involvement in research related to IFA should continue.
2. Preventing the spread of the IFA should not be considered justification for funding federal control programs. Operating inspection and quarantine programs to protect uninfested areas is justified.
3. Treatment costs should be borne by the direct beneficiaries such as farmers and property owners.

Data for estimating costs and benefits

1. Immediately begin collecting information on damages and benefits of IFA control, relying principally on the informed judgment of experts in the field. These experts should draw on available research information, but rely heavily on their own field experience. Develop a structural process for collecting and evaluating the expert judgments. One such method is a delphi-type approach. This should be a joint federal/state activity.
2. Utilize the data to assess the economic and social implications of alternative control options following accepted analytical procedures.
3. Analyze the strengths and weaknesses of the data and develop longer term research, data collection, and monitoring plans to improve the data. Initial attention should focus on data items that are most critical and least reliable. A workshop could be held to determine and establish research, survey, and monitoring priorities.

Education, training, and extension

1. Devote new resources to IFA information and training activities. This should be the lead responsibility of the Cooperative Extension Service, U.S.D.A., public schools, and other agencies.

Research in IFA and its management

1. Research must be done on the perceptions of homeowners, farmers, and other groups as to (1) the IFA as a pest, (2) pesticides, (3) pesticide hazards, and (4) willingness to contribute to IFA control.
2. Conduct a detailed epidemiological study in IFA-infested areas to estimate the size of the human population at risk from IFA stings, the frequency of health effects, and their significance.
3. Better coordinate and target research efforts on the biology and control methods of the IFA.

IFA management on federal/state lands

1. Federal/state agencies responsible for managing lands subject to IFA infestation should develop IFA management programs that are consistent with economic thresholds.
2. Agencies should demonstrate IFA management practices that can be emulated by private land managers on similar type sites.
3. State/federal management demonstration projects should be coordinated with research and extension programs.

FOOTNOTES

[1] In addition to other currently registered pesticides.

[2] Costs were calculated using 1982 prices, even though costs in future years would be higher due to inflation.

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TABLE 1

PROGRAM: Aerial eradication

PROGRAM DESCRIPTION:

1. Federal/state financed program to eradicate IFA
2. Three treatments over about 18 months
3. All infested acreage treated

ACRES TREATED:

1. Slow approach

1st year	7 million
2nd year	14 million
3rd year	21 million
4-33rd years	21 million/year

Total acres = 230 million x 3 = 690 million

2. Faster approach (3x the slow approach)

11 years total
21 - 63 million acre applications per year

TREATMENT COSTS:

1. Slow approach

Slow approach	Amdro	Ferriamicide
1st year	$35.00 million	$17.5 million
2nd year	70.00 million	35.0 million
3rd year	105.00 million	52.5 million
4-33 years	105.00 million	52.5 million
Total	$ 3.45 billion	$1.725 billion
Cost/acre	$5.00	$2.50

2. Faster Approach

Same total as above, but increases sooner, thus saving costs of inflation.

FEASIBILITY ASPECTS/LIMITATIONS:

1. Legal problems preventing complete area coverage essential for eradication.
2. Funding limitations—other claims on funds are likely to have higher social priorities.
3. Speculative nature of the biological success.
4. Program management, logistical and quality control problems due to program size.

TABLE 2

PROGRAM: Aerial suppression

PROGRAM DESCRIPTION:

1. Federal/state/local cooperative financing

   a. One-third

Fed	33%
State	33%
Local	33%

   b. Fed matching

Fed	50%
State/local	50%

2. Suppression to lower populations in large scale areas.
   Large area treatments are designed to decrease resurgence. States likely to take initiative on general areas and number of acres to be treated.

3. Open market sales of chemical for ground broadcast and mound-to-mound treatment.

ACRES TREATED:

1. Principal sites

   Agriculture: Pastures, hayland, fencerows, farmsteads, hand labor crops and generally where problems are most severe
   (Some row crops)
   Non-agriculture: Lawns, campgrounds, school yards, other public outdoor meeting places, cemeteries, etc.

2. Acres

   10-30 million/yr., depending on financing and state/local interest

TREATMENT COSTS:

Amdro	\$50-75 million/yr. (\$5.00/acre)
Ferriamicide	\$25-75 million/yr. (\$2.50/acre)

FEASIBILITY ASPECTS/LIMITATIONS:

1. Funding limitations could be quite significant.

2. Some legal problems, but less severe than eradication.

TABLE 3

PROGRAM: Aerial relief (subsidized)

PROGRAM DESCRIPTION:

1. Individual landowner pays one third of total cost of treatment ($1.66/acre for Amdro and $0.83/acre for Ferriamicide)
   Federal/state pay remaining 2/3 of cost

2. Temporary relief to individual property owners with more rapid resurgence than with large scale suppression program. Treatment lots would range in size from 40 acre minimum

3. Open market sales of chemicals for ground broadcast and mound-to mound applications

ACRES TREATED:

1. Principal sites

   Agriculture: Pasture, hay, intensive labor crops and especially farmsteads.
   Non-agriculture: Lawns, school grounds, campgrounds and other public places

2. Acres/yr.:

	Amdro	Ferriamicide
Acres/yr.	3-5 million	5-10 million

ANNUAL TREATMENT COST:

Amdro	
Landowners	$ 5-8.3 million
State/Fed.	10-16.7 million
Total	15-25.0 million

Ferriamicide	
Landowners	$ 4.1-8.30 million
State/Fed.	8.4-16.75 million
Total	12.5-25.00 million

FEASIBILITY ASPECTS/LIMITATIONS:

1. Operational and legal problems do not appear to be critical.

2. Dependent upon availability of public funds which may have higher priority uses.

TABLE 4

PROGRAM: Landowner Relief (no subsidy)

PROGRAM DESCRIPTION:

1. Individual landowner pays total cost of treatment ($6.00/acre for Amdro and $2.25 for Ferriamicide).

2. Temporary relief to individual property owners with more rapid resurgence than with large scale suppression program.

3. Open market sales of chemical for aerial and ground broadcast and mound-to-mound applications.

ACRES TREATED:

1. Principal sites

   Agriculture: Pasture, hay, intensive labor crops and especially farmsteads.
   Non-agriculture: Lawns, school grounds, campgrounds and other public places.

2. Acres/yr.:

	Amdro	Ferriamicide
Acres/yr.	2-4 million	4-8 million

ANNUAL TREATMENT COST:

Amdro	
Landowners	$12-24 million/yr.
Ferriamicide	
Landowners	$9-18 million/yr.

FEASIBILITY ASPECTS/LIMITATIONS:

1. Operational and legal problems do not appear to be critical.

2. Program effectiveness limited where landowners lack pest management information for IFA control.

Table 5. Summary of key findings on four sample alternative imported fire ant control program approaches.

Program Approach	Objective/scope	Cost	Evaluation
1. Eradication	Complete elimination of IFA from 230 mil. acres, over 11-33 yr. period	Amdro a) $35-315 mil./yr b) $3.45 billion total Ferriamicide a) $17.5-157.5 mil./yr b) $1.72 billion total	Definitely not prudent due to lack of feasibility and adequate resources; severe legal problems. (e.g. environmental groups and non-cooperative landowners)
2. Suppression (Large area)	Sustained control with minimum reinfestation on priority land areas (10-30 million acres treated/yr.)	Amdro $50-75 million/yr. Ferriamicide $25-75 mil./yr.	Not adviseable, given the level of benefits to be achieved relative to costs; significant legal and funding problems for full scale program.
3. Subsidized relief	Temporary relief to owners at one third treatment cost as requested by owners; 3-10 million acres/yr., lawn, school, recreational, farmstead and priority ag. lands	Amdro Landowners $5-8.3 mil./yr. Government $10-16.7 mil./yr. Total $15-25 mil./yr. Ferriamicide Landowners $4.1-8.3 mil./yr. Government $8.4-16.7 mil./yr. Total $12.5-25.0 mil./yr.	Feasible; scope depends upon availability of funding and level of subsidy per acre treated.
4. Non-subsidized relief	Temporary relief at full market price to landowner a) Amdro: 2-3 mil. acres b) Ferriamicide: 4-8 mil. acres	Amdro $12-24 mil./yr. Ferriamicide $9-18 mil./yr.	Market solution feasible provided no government subsidies or interference in market; costs to be incurred in line with benefits.

PANEL II

THE THEORY OF POPULATION DYNAMICS

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INTRODUCTION

When studying a group of insects, we are often overly impressed by their presence and number. When numbers are high, economic entomologists usually locate the point of highest density and count the individuals. From this estimate, the "outbreak" is characterized and control recommendations are presented, with the underlying belief that if sprays are applied at points of highest density, we will get the most kill for control cost and therefore the most benefit. The complex interactions of a pest population with its biotic and abiotic environments renders these assumptions and approaches to a useless leftover from the chlorinated hydrocarbon era. The lack of understanding about the interaction of individuals within a population leads to many, often counter-intuitive, outcomes. For example, every individual will die from natural causes without human-imposed controls. Thus, killing a pest with a pesticide usually brings about damage control through population reduction, but not population control. This fact appears trivial, but perhaps is the most significant point in population dynamics.

THE THEORY OF POPULATION DYNAMICS

When considering the applied and theoretical aspects of insect populations, the organizational levels where interactions occur should be considered. Basically there are four levels of generalized pest insect groupings: subindividual, individual, population, and community. Difficulty raises when observations are made at one level and the implications are projected to a different level. The key to understanding most "single-organism" populations is the population; therefore, individuals must be counted. This simplistic idea becomes a complex issue with social insects or what might be considered as "multi-organism" populations.

For the purpose of this report, we can define "population dynamics" as a discipline that studies the factors producing change in the number and quality of individuals. The term "population" as it relates to insects is ill-defined and takes on meaning only from the context in which it is used. As such, one ecological definition might be: a population is a group of individuals sharing a common gene pool. Unfortunately, the operational definition is usually: a population is a group of individuals occupying an area defined by our concern for considering it as a population.

Thus, a crop pest becomes defined as a population with little concern for its linkage with other individuals outside the crop. This operational differential may be a philosophical side effect of using pesticides. Pesticides applied to the crop kill a large number of insects present or soon to arrive. Defining the population as individuals living or dead in the crop results in high kill statistics. If 1% of a population resides in a crop and 99% are killed, it is not very impressive to state that slightly less than 1% of the population was destroyed.

In a community, groups of individuals live together in some sort of natural order. The temporal and spatial aspects of a community do not need to coincide with a specific population. Communities are complex biological, social, and ecological webs. Managing such structures could be the most important, and largely untapped, non-chemical control method for any species. Thus, community structural modification research should be a high priority.

Adding the word dynamics to population implies a change over time. To understand this, it is essential to realize that a population is distributed over time and space. The spatial distribution is normally used during pest surveys, with results expressed as pests per sample, pests per field, etc. The temporal aspects such as age structure and population maturity and distribution, are seldom addressed even though they are equally important. Both spatial and temporal aspects of a population interact in a way that appears to be opposite or in conflict with simple intuition.

For example, Figure 1 is a typical problem associated with sampling insect numbers to compare spatial differences. The population remains relatively constant until March, when it reproduces rapidly until May. Natural mortality causes a decline until November. Sampling this population would result in densities varying from 10 to 60 on this theoretical curve. The significant parameter represented by this graph is not the six-fold difference in density, but the generation index of I equal to one where I = (density March 1, year 1) ÷ (density March

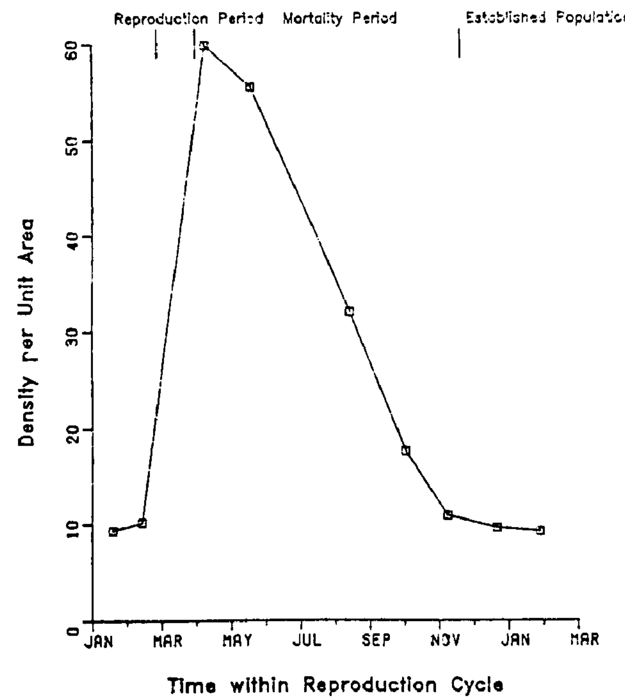

Figure 1. Example of an insect population density through time.

1, year 2) = 1. This population has not changed, but its calculation required both time and spatial components to be accounted for. Population diagrams invoke the analysis of number over both time and space. In essence, timing of such measurements is critical to getting a true picture of the insect's population. As simple as this idea is, however, it is rarely practiced.

Most historic literature in animal ecology has analyzed factors that limit or control population numbers, and the relative importance of abiotic and biotic components of the habitat have been argued. Only recently have individual populations and community structure been linked in highly interdependent models representing natural systems. Linkage between abiotic factors and the biotic components of the ecosystem can be direct and indirect, with or without time delays. Since these linkages and interrelationships are often complex, a sound theoretical framework is helpful for interpreting the effects that management practices may have on population performance and community structure.

DIFFERENCES IN PESTS

In American agriculture there appears to be four classifications of "emergency pest problem," each requiring a different pest management response:

1. Exotic pests: These are newly-introduced pests whose populations rapidly expand to high numbers before slowly adapting to the new environment. Insects in this category are cereal leaf beetle, gypsy moth, imported fire ant (IFA), Japanese beetle, winter moth, European pine sawfly, Essex skipper, European skipper (McNeil 1975), and alfalfa weevil.

2. Native pests with cyclic outbreaks: Because they are so closely tied with the environment, these pests go through periodic outbreaks. Pests in this category would include spruce budworm, grasshopper, range caterpillar, hemlock looper, bark beetle, etc.

3. Native species with expanded range: This pest species exists in limited geographic areas or environmental habits and adapts to new hosts or climate conditions. Insects such as the Colorado potato beetle, bean leaf beetle (Dietz et al. 1976), apple maggot, boll weevil, and corn rootworm belong in this category. Included could be pests developing additional generations in response to agricultural production practices, or the release of resistant varieties (e.g., Hessian fly). Pests developing resistance to chemicals also could fall with this category.

4. Induced outbreak: This category includes most secondary pest insects that build up in pesticide-impacted environments when the pesticide is not directly applied for their control. The category would include such pest species as spider mites, aphids, and numerous lepidopteran pests.

The response by governments and similar institutions to pest outbreaks needs to carefully consider the unique population characteristics associated with each category. An effective management response may be very different for each situation, and a single control option may have very different outcomes in different classifications.

ECOLOGICAL PHASES OF INTRODUCED PESTS

In this section, we will track the ecological progression of an introduced (exotic) pest as it adapts to its new environment.

During a new introduction phase, the insect rarely is adapted to or closely coupled with the ecosystem. At this time, the abiotic environment exerts several pressures on the insect population. It determines the physiological limits for colonization and whether the insect will survive. Understanding the physiological limits will help determine how successfully the species will colonize. Knowing how climate affects survival and movement will help determine how effective a pest the insect might become. Also, understanding the abiotic effects on the population will aid in predicting whether the new introduction or indigenous species, occupying the same niche, will be favored in a competitive interaction. These predictions will be useful when evaluating management tactics. For example, a broad spectrum biocide that disrupts existing communities could lead to a more successful establishment of an introduced species.

After the new introduction phase, insects go through a physiological adaptation stage. Life table analysis of this phase could indicate windows of vulnerability in the pest's life system, such as periods of stress. Exploiting these vulnerable times could result in successful management strategies (i.e. disrupting overwintering sites). Included in this phase is genetic adaptation. During colonization, insect pests are subjected to new selective pressures as a consequence of changes in the abiotic and biotic components of the environment. Populations that succeed in surviving the genetic selection may have acquired a radically altered, balanced, genetic system. Such genetic evolution is observable in terms of morphology, physiology, behavior, and life history traits. The alterations can be so drastic that the introduced population can be considered to be a new race or even a new species, complete with pre- and post-mating isolating mechanisms. In terms of pest control, this means that an introduced species has, in its new environment, the potential to evolve in an unforeseen manner (Templeton 1979).

The final phase of colonization is the successful physiological adaptation of the insect. At this time both competitive and predator/parasite relationships are important, which typically results in the pest status of the introduction being less than the previous stage. Again, abiotic factors may alter competitive relationships between the pest and its natural enemies.

By knowing the effects that weather, community structures, and their interactions have on pest populations, it is possible to predict when and where pest populations will occur. This information also can be used to avoid control tactics that adversely disrupt the system. Humans can greatly impact the natural evolution and adaptation of exotic species to its new environment by stopping and, in some cases, reversing this natural progression.

THE WORLD: A BUG'S POINT OF VIEW

Elephants and hippos do not get caught in water surface tension. Insects do. Understanding the needs and dynamics of a population requires that we imagine things in the way that a species must see them. The microclimate experienced by a particular species is not necessarily that reported by the U.S. Weather Service or measured in a weather shelter. Often that species has evolved over millions of years to become adapted to a particular environmental niche. The fact that is becomes a pest may simply be a consequence of our inadvertently expanding its niche space a million-fold or so with bulldozers and tractors or accidental movement. When this happens, we might consider possible ways to shrink the microclimate niche space. If this can be done while still achieving system goals, then the pest may be reduced to non-pest levels. Understanding the microclimate of the pest could lead to the development of interesting management options. The literature is replete with such examples.

OPPORTUNITY IN A CRISIS

A unique opportunity exists in social insects to research the effects of individual quality on population dynamics. By defining a colony of social insects as an "individual," the individual quality and its effects on the population of such individuals becomes easier to research and model. Model resolution increases. In fact, for a community of ant species, many levels can be identified and measured fairly easily. Levels start with a species; within a species there is an age of nest; within that level there is a distribution of ant types; and within that level there is an age distribution. This complexity is measurable for most insect populations only with enormous resources. For ants, however, the within-nest dynamics can be measured and studied fairly easily; the direct effects of changes of within-nest distributions (age and type) can also be modeled. Such models will help integrate a research program much more than is usually possible. With increasing complexity models become more realistic, which increases the level of understanding of the population and its interactions. This is particularly true when measuring abiotic stress on within-nest dynamics. Models that effectively incorporate abiotic stress are difficult to develop for non-social pest populations.

POPULATION ANALYSIS

Measuring an Abstraction—Determine Sampling Attributes

All populations share certain life processes. For example, the development rate of all insects is temperature-dependent. Thus, both physiological and chronological time scales should be used when measuring life processes. Many processes that occur (e.g., reproduction, mortality, movement) are related to the density of the target species and/or other species.

An important concern in dealing with social insects is that different processes affect the individual and the colony differently. Understanding the individuals' dynamics does not necessarily imply a knowledge of colony dynamics and vice versa. Because of this hierarchy, it is imperative that processes be examined at the appropriate level. Thus, if one is concerned with managing a social pest and the target is the colony, colony dynamics should be most closely examined. Given this background, the major sampling considerations are:

(a) selecting the sampling entity (individual, cluster, colony),
(b) selecting the sample unit (square meter, soil type, habitat, etc.),
(c) selecting the spatial and temporal sampling intervals,
(d) determining the type of distribution(s) observed and any changes associated with other population and habitat characters, and
(e) calculating the sampling schemes for various specific objectives.

All sampling plans must provide error estimates and make variance partitioning possible. The necessary data to establish these sampling attributes can come from early phases of concurrent research that includes changes in (1) the pest: numbers of individuals and individual attributes, and (2) the environment: physical and other organisms (plants, competitors, enemies, and commensals). In social insects, where the unit of study may not be the individual, nest or colony characters have to be measured to give the colony some specifically identifiable states (i.e., all colonies are not equal). These studies should be conducted extensively (coarser sampling over wide areas) and intensively (including the extreme situations).

Population behavior of new invaders, such as the IFA, may change dramatically through time. Inferences drawn from the study of invading populations along the advancing front of an infestation must be interpreted cautiously. For example, populations of the sea lamprey virtually exploded when the species reached the Great Lakes. Despite aggressive control efforts, predation on lake trout devastated that fishery. Now, however, lamprey predation is scarcely a factor in the booming sport fishery for the several salmonid species introduced from the Pacific. For this reason, it is particularly important to encourage studies explicitly designed to detect and interpret long-term changes in population behavior. Specifically, some areas should be reserved for long-range (perhaps 20 to 30 year) studies on the population dynamics of the IFA.

From this work, correlations can be found between the pest and its environment. Typically, these become the basis for generating hypotheses about cause and effect relationships. These hypotheses need testing. As correlations are developed, emphasis should shift toward experimental studies designed to test these hypotheses, rather than to assume their validity. Initial research should concern hypotheses that appear most crucial to conceptualizing the pest system. Since more than two alternate hypotheses may explain any single correlation, the researcher should consider all hypotheses and design research to differentiate among them. Once a given hypothesis is confirmed, the general conceptualization should be updated.

At any time, both the scientist and the granting and/or regulatory agency can use this construction when making judgments on current research or management requests. However, both the researcher and involved agencies should avoid (1) studying only those aspects that have immediate management applications, or (2) continuing, ad infinitum, studies of relationships having no known potential for management.

ANTS AND WHAT TO LOOK FOR— A PARTIAL LIST

As in all other cases, the attributes of a system are determined by the questions and hypotheses guiding the study. The following example concerns the community dynamics of ants. Since the level of study has been defined at the community level, measurements are restricted to processes that feed into determining community dynamics. Thus, many features may be excluded entirely and treated as a "black box." For example, for some purposes, the mechanisms of pheromone production and distribution within a nest may be ignored; integration of nest activities becomes a product of a "black box" hormonal system. However, the decision to exclude the mechanics of a process has to be chosen carefully. For example, ignorance concerning the functional details of mammalian hormones may be acceptable when studying the interactions of ungulates, but it would be essential to rodent interactions where adrenal gland weight and activity relates to behavioral dominance. The point is to be cognizant of the role of hormones/pheromones in ant community dynamics and to carefully choose the level of measurement that meets the requirements of the guiding hypotheses and questions.

Some examples and rationales for selecting sampling attributes of community dynamics of ants include the following, very incomplete, variables.

1. Species-specific foraging behavior: Shifts in the time or location of foraging in the presence or absence of other species (e.g., McNeil et al. 1978) may indicate important competitive interactions and could, under some circumstances, feed into the community structure.

2. Spatial distribution of nests: For this study, movement of workers of the same species from nest to nest validates the use of the nest as the sampling attribute. The distribution of nests of each species and their abundance through space and time is the appropriate sampling unit to measure the outcome of community interactions. The distribution of foraging workers around each nest may be the more appropriate sampling unit for measuring the interactive mechanisms of community change.

3. The dynamics of the community: Change, resistance to change, and rates of return to the original community composition are the focus. Therefore, experimentally, nest distribution is appropriate. For meaningful results, conditions must be specified (e.g., which environment, over what time course, the initial set of populations, etc.).

SOCIAL INSECTS: PROBLEM OF DEFINITION AND BIOLOGY

Relative Time as a Problem and Opportunity

For most pests in annual cropping systems, the periodicity of the habitat is long relative to the generation time of the pest. With many species, the reverse is true. The lifespan of a particular crop is generally shorter than the generation time of the resident social insect colony. Short-generation pests that spend much or all of their lives in a single environmental patch should follow the environment closely (i.e., become specialized for particular field types). Long-generation pests and pests with low dispersal thresholds should be relative field generalists. Thus, habitat manipulation as a control procedure for long-generation pests may have limited success unless the alternating habitats (in time and space) are chosen on the basis of knowledge concerning environmental determinants of population dynamics.

Population Processes

Birth-death processes in social insects are similar to other organisms, but some important differences exist. Obviously, the addition of sterile workers is simply individual growth of the colony; the colony is the organism from the perspective of population dynamics. As the colony adds or subtracts workers and adjusts the caste composition, the colony changes its ability to meet the various life contingencies of reproduction (new sexuals leaving the colony), competition, nest repair, etc. That is, the colony has various age or stage-specific parameters. In cases where queen substitution occurs, the colony is, in principle, immortal. Concepts, such as reproductive value, become stage-specific properties, and "life" expectancies become the set of transitional probabilities of death associated with each stage. The possibility of polygyny (multiple queens) occurring in social species means that fecundity will be highly variable within a species; it then becomes necessary to treat variance as a parameter in a life system model. Death of queens in polygynous colonies is treated as an effect on reproductive value. This explanation of birth-death processes illustrates the equivalent processes in social and solitary species. These processes, however, may be difficult to measure.

The colony is a responsive homeostatic system with many paths for feedback loops and mechanisms for controlling flow rates along the loops. For example, a colony has four levels of buffering against the morbidity effects of a variable food supply.

1. The colony can store food in the nest; therefore, foraging and harvesting rates are not limited by the immediate metabolic needs of the colony. Furthermore, saturation curves for foraging behavior may not be closely correlated to colony biomass but may be limited by environmental, temporal, and spatial patterns of food availability.

2. The ability to change foraging behavior relates to the abundance and distribution of food outside the nest. For example, an ant colony may forage by using a few well-defined trails when food is predictable and clumped. When food is unpredictable and dispersed, the colony may switch to diffused foraging behavior without defined trails.

3. Larval secretions may be used to feed other larvae and workers, which distributes the food within the colony to prevent local shortages among some larvae.

4. Larvae may be cannibalized (actually a form of colony catabolism) as food for other larvae. There is considerable fine tuning in this behavior. For example, since eggs have received little colony investment, they are the first stages to be used as food. Sexual larvae are fed preferentially, thus maintaining reproductive success.

Relatively little seems to be known about the population dynamics of social insects. Even age at death, a straightforward attribute of individual insects, may be difficult to define for a colony or nest. While the members of this panel had relatively little experience dealing analytically with such unique attributes, they judged that current analytical methods can easily be modified to incorporate these unique features.

GENETIC CONCERNS: A CASE OF NEGLECT

Problem or Opportunity

Genetic systems of social and non-social insects are similar in some respects, but different in others. In non-social insects, bisexual reproduction of diploids maximizes genetic exchange and thus maintains a high level of genetic heterogeneity in the species. In social Hymenoptera, males develop from fertilized eggs and are haploid; the females, from fertilized eggs, are diploid. This genetic system is known as haplodiploidy (Wilson 1971, Crozier 1977). A connection between haplodiploidy and the frequent occurrence of sociality in insects has been suggested by several researchers. This system allows considerable inbreeding and thus maintains a high degree of homogeneity among social insects. Recent biochemical evidence from gel electrophoresis of isozymes reveals that the average heterozygosity of social insects is considerably lower than that of non-social insects (Crozier 1977, Ayala 1982). Such low genetic variability in social insects confirms that there are specific differences between the genetic systems of social and non-social insects.

The development of social systems involves many changes in the characteristics of social species that are not found in non-social insects. Many behavioral and ecological interactions that are integral parts of a social system have no parallel in non-social insects. Regarding the reproductive potential, social insects are often thought of as having unusually high fecundity. The task of reproduction in social insects, however, is carried out by one or a few reproductives; in non-social insects, all females contribute to the reproductive task. When comparing populations, the reproductive potential of the two insect systems is probably similar. A special feature of social insects is that the reproductives are protected in the nest and are seldom subjected to adverse environmental conditions. Since most of these species have a long generation time, they are less affected by natural selection pressures. This may be one of the reasons why social insects appear to develop resistance to insecticides at a much slower rate than non-social insects.

Community Analysis

Performance of a population depends on the combined effect of the individual attributes of the population plus the total interactions of other populations occupying the same geographic region. Analysis of the nature of the interactions between populations, and the results of these interactions in terms of stability, persistence, and dominance, is the topic of community ecology. Community ecology, therefore, can be used in understanding the effects of complex interactions (i.e., competition and predation) on the abundance of particular pest populations.

For an introduced pest, which progressively becomes more adapted to new ecological associations, particular community-level associations may be more important during certain phases of adaptation than at other times. For example, during the early stages of colonization, competition with native species occupying a similar niche would be the most important community-level association. In later phases of adaptation, relationships with natural enemies would become important.

A CASE FOR MODELING

Our understanding of the actual population dynamics of organisms can be greatly enhanced by considering the diversity of behavior of population models. Even very simple models of a single species can exhibit a vast array of possible behaviors. This type of complexity can usually be obtained by varying the "constants" in the model, which is analogous to making them functions of time or space in a very general sense (to what actually happens in the real, "non-constant" world). That very simple models of one or two species exhibit complex behavior when subjected to this type of analysis is encouraging to the population biologist. It implies two things: (1) predicting complex behavior of the real world is within the scope of relatively simple models, and (2) real world complexity can be reduced to simple components.

Simplistic population models showing that a wide array of behavior is possible also says something to humans about population management—ecological communities will not have simple responses to simple inputs. Surprises will be the order of the day. There are no simple rules--just exceptions. Good management is possible, but it must be long-range and founded on knowledge. Given the complexity of the simplest ecological community, ill-considered, forceful, management attempts will simply produce large perturbations with uncertain consequences. The worst enemy is ourselves—our haste for a quick, simple solution, rather than a desire to understand the problem (Stinner 1982).

HIGHER ORDERS OF INTERACTION

The environment largely determines how a community will move through time and space. By varying the "constants" in simple models, very complex behavior can be obtained. Therefore, when these "constants" in a community are actually environmental functions, the environment drives the community dynamics. Even the most gross level of dynamics (e.g., establishment of a new species) is obviously a function of temperature, rainfall patterns, etc. Therefore, it should not be surprising that even simple species interaction models display remarkably different behaviors in response to only one variable, like temperature. As temperature changes, a pest and its natural enemy may change in their interaction from damped cycles to constant cycles to increasing cycles to chaotic behavior. This change in behavior could occur over the course of an annual cycle or over the species' geographic range in response to temperature. We must understand that simplistic thinking about biological responses to environmental influences is not likely to be correct. The rich diversity of possibilities will not be predictable.

In agricultural systems, perhaps excluding tree crops and permanent pastures, communities of pests are unlikely to be at near-equilibrium conditions. Under these conditions, much community ecology theory is inapplicable. The appropriate development of a theoretical basis for an agricultural community ecology should consider the following:

1. Perturbation analysis with an emphasis on resistance and resilience.

2. Methods of analysis, e.g., loop analysis as developed by R. Levins, appropriate to complex systems where many interactions can be expressed only in qualitative form.

3. The relationship between changes in the connections between species and what happens to the form of stability. This requires an analysis of the hierarchical pattern of species links within the community. It is important to identify subsets that are connected to the rest of the community by single links.

4. The relationship of resource utilization curves as a function of community composition and local habitat. In other words, in which habitat and for which permutation of species mixtures do we find minimum and maximum overlaps in species resource utilization curves.

The goal is to develop procedures and generalizations such that community level management can systematically and predictably determine the probability of invasion by a new species. With regard to the IFA, it is frequently asserted that no natural enemies or important competitors exist. Since the IFA is abundant and expanding its range, the IFA seems to be independent of competition and predation from other species. However, this assumption ignores the reality of considerable local variation in nest density and colony abundance. When the IFA is abundant it is said to lack competitors and predators, but when it is scarce, the IFA is said to be in a "poor habitat." Thus, the possibility of biotic controls on IFA population dynamics is semantically excluded. Clearly, the proper natural laboratory for the study of the population dynamics and community ecology of a pest is across an array of habitats where the proportional representation of the pest in the community ranges from "frequently absent" to "usually abundant."

CONCLUSIONS

Research and Resources

As applied biologists, we often have heard: "The problem is here now! We must do something! We cannot wait for research." If this policy of ignorance were only words and not subsequent budget adjustment, there would be more hope. There are at least two ways to manage crisis: one is to prepare a program of action in ignorance, and the other is to prepare a program where at least one outcome is a significant increase in our understanding of the problem. Research does not have to be considered as a noble human endeavor conducted outside of immediate need or, conversely, conducted solely for the purpose of immediate application. Both approaches perpetuate our initial ignorance for future consideration. Neither has a high probability of success. Our lack of basic understanding of IFA population dynamics after more than two decades of government response is a specific case in point. The policy, "the only good insect is a dead insect," has not worked and cannot be expected to work. *It should be a given policy that, in any control response (eradication, containment, management), failure is possible.* Thus, modest funds should be provided for long-term study of the population dynamics of the species at the onset (or certainly within six months) of eradication attempts.

Historically, there has been a strong reluctance to provide these funds since it admits potential failure of the present program. If it was a general policy to provide research funds, then the political problems associated with an admission of potential failure are avoided. All efforts at challenging a newly invading species should include an initial conceptualization of the population dynamics of the species. This construct must be flexible and should be updated as new information is obtained.

To blame institutional response totally for perpetuating biological ignorance of invading pests would be a gross oversimplification of the problem. Clearly institutional inertia and political expediency are dominant factors in resource allocations for program development. However, the lack of resources for basic population research cannot be strongly implicated in closing minds or the inability to conceptually interpret existing information and theory related to other animal populations.

Economic entomologists and pest control specialists in particular dwell on the uniqueness of each pest subdivided into each crop. If, on the other hand, biologists were looking for theoretical bases for examining apparently dissimilar events, a great deal of information could be brought to bear on particular problems. The case in point is that IFA research should look for population principles in other pest species instead of treating IFA characteristics as if they were unique.

Single Factor Control

In given pest situations we tend to attack the pest directly with mortality agents whose action is often non-specific. Natural enemies, competitors, and disease agents may be exerting a very high, and continuing, mortality on the pest despite its pest status. If this complex is disrupted, the pest, usually having a high reproductive potential, is released from much of its mortality pressure. The result is the often observed pest resurgence phenomenon; in addition, new pests can be created by indiscriminately removing their mortality agents. Thus, knocking out a section of a community without being sure of what will happen can produce undesirable surprises.

Community Structure

We must understand and manage at the community level. We are part of the community that we seek to manage, and we cannot escape its feedback if we completely ignore its structure and proceed in heavy-handed ignorance. The scientist needs time and support to obtain the basic knowledge necessary for any intelligent management program. Large-scale programs covering millions of acres should never be undertaken until a high level of understanding of the system has been obtained. In fact, in many situations, once that level of understanding is obtained, we will probably have resolved the system into several sub-systems each requiring a somewhat different program of management. There are few simple solutions to managing community ecosystems. If we apply the intelligence we have to the management of ecosystems, we probably can be successful in many cases. If we do not apply that intelligence, it is most likely that the ecosystems we seek to manage will control us.

Genetic Analysis

Genetic analysis of insect populations, especially pest species, has been a neglected field of research. Extensive research data will be needed before any generalization can be made about the genetic systems of pest species. Since population is the basic unit of ecology and evolution, the study of genetic variation should be focused at the population level to determine the genetic components that influence population processes. Many fruitful approaches are available for genetic analysis of social and non-social insects. Techniques such as chromosomal karyotype analysis, gel electrophoresis of isozymes, and DNA sequence should be routinely used for genetic studies. In addition, various ecological, physiological, and behavioral traits of pest species should be monitored to determine population variations. Traditional crossbreeding experiments will also be needed to define genetic mechanisms of inheritance. Since most of these studies require a long time, adequate duration of time and financial support must be available for such research programs.

Evidence of high genetic variability in insects reflects the tremendous evolutionary potential of pest species; control programs should be designed with this in mind. Probably no single perfect control method exists against an insect pest since the insect is likely to evolve resistance. However, evolutionary theory predicts that an insect pest is far less likely to evolve resistance to a control program where many strategies are used. In general, therefore, a control program that incorporates multiple approaches is the best type of program. In order to employ multiple-approach control strategy, basic knowledge of the ecology and genetics of pests and related species must be available, and only through application of such knowledge can the control options that exist and their respective risks be dealt with. Therefore, for the development of a long-term control program, there is an immediate and critical need to increase basic research on the ecology and genetics of pests and related species.

RECOMMENDATIONS

1. Funds should be provided for long-term study of the population dynamics of the pest species at the onset of any eradication trials for any pest.
2. Research on the IFA should examine the population dynamics of other pest species and compare them to the IFA.
3. Single-factor control should not be a priority in control strategies, rather emphasis should be placed on multi-factor management strategies.
4. A conceptual framework for dealing with the population dynamics of the IFA needs to be developed.
5. Modern experimental design, analytic, and measurement tools should be used to study the population dynamics of the IFA.
6. A workshop of researchers studying population dynamics of the IFA and of other species should be held to pool knowledge and develop a sound system for studying

the population dynamics of the IFA.

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PANEL III

POPULATION DYNAMICS OF THE IMPORTED FIRE ANT

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INTRODUCTION

The imported fire ants, *Solenopsis richteri* Forel and *Solenopsis invicta* Buren were introduced into the United States in the early 1900's and late 1930's, respectively, at the port of Mobile, Alabama. The spread of these ants, primarily *S. invicta*, from this area was dramatic. Surveys conducted by the U.S. Department of Agriculture in the late 1940's and early 1950's revealed that IFA were present from Miami, Florida, to San Antonio, Texas, and as far north as Memphis, Tennessee, and eastern North Carolina. Today it is found on about 240 million acres in ten states; within this geographic area, mound densities range upward to 600 per acre. *S. invicta*, the red IFA, occupies over 95% of the infested area, while *S. richteri*, the black IFA, infests northern Mississippi and Alabama.

IFA are found in many habitats, but tend to favor open or sparsely-forested areas. Levels of infestation vary widely within the habitat types. However, the factors influencing these levels are not clearly defined.

EXTRINSIC FACTORS

Abiotic

The role of abiotic factors, especially temperature and humidity, on the distribution and abundance of IFA are being investigated. Because the IFA prefer high relative humidities and moderate temperatures, they probably will not spread further north, although they may be able to survive in protected areas if accidentally introduced.

Natural spread of *S. invicta* through the desert southwest will be very slow if it occurs. However, based on comparisons with closely related *Solenopsis* species, *S. invicta* probably can establish and survive in the southwest and along the west coast. Artificial introduction by human activities may greatly hasten spread through this area.

The effect of moisture (mode, amount, and timing) on reproductive potential is unclear. Variability in this factor may strongly influence the ability of the ant to produce mating flights and colonize the southwest and far west.

Biotic

Despite intensive searches, no effective parasites or pathogens on the IFA have been found in the U.S. Predators have been found, but their role in regulating IFA populations has not been studied in depth. *S. invicta* queens are attacked and killed by a variety of predators from the time they take flight until they successfully establish a colony. *Neivamyrmex opacithorax* has been reported to prey on larvae of *S. richteri* Also the thief ant, *Solenopsis molesta*, has been found living in the nests and preying on the eggs and young larvae of both IFA species. In southern Mississippi, the ant, *Paratrechina melanderi*, has been found preying on *S. invicta* eggs.

The IFA in South America are beset by a number of diseases, parasites, and competitors. Thus far, none of these have been shown to influence population density; however, this may reflect a lack of detailed studies that could be alleviated if long term research in South America were performed by competent scientists provided with adequate technical support.

Although no definitive studies have been conducted on habitats prior to and as the IFA colonizes an area, observations indicate that the IFA populates new areas with 15 to 40 mounds per acre. In areas where control measures have been applied or other ecological disturbances have occurred, a large number (100+ per acre) of small colonies may establish a year or two later. In time the number of colonies decreases to predisturbance levels or higher. These temporal changes in IFA populations may be due to intraspecific competition among *S. invicta* colonies and interspecific competition among *S. invicta* and other ant species. Such inter- and intraspecific competition needs to be studied.

S. invicta is an efficient colonizing species with a high reproductive capacity and excellent dispersal and habitat-finding abilities. This opportunistic species thrives in areas where lands are disturbed by any means (e.g. flooding, cultivation, and insecticide applications). In addition, once the IFA successfully colonize an area, there are no known competitors that can displace the IFA. Therefore, any management strategy should be directed at imposing mortality on IFA queens at rates that are discriminantly higher than mortality imposed on other ant species. Control tactics imposing indiscriminant mortality on all ants may strongly select for proliferation of the IFA.

INTRINSIC FACTORS

Reproductive Potential

One of the primary reasons for the success of the IFA in the United States has been their reproductive potential. The number of reproductives, frequency of flights, and climatic conditions are major factors in determining distribution and rate of spread. Most IFA mating flights occur during late spring and summer, but they may fly anytime during the year. Studies have shown that flight range depends on wind speed, rainfall, and temperature. Most queens land within a few miles from the source, but distances up to 12 miles have been documented, and it is suspected that the range may be much greater. Rate of spread has not yet been accurately ascertained.

An IFA colony may produce three to five *thousand* queens per year. Winged (alate) forms were trapped leaving mounds in four habitats in north Florida, and it was estimated that an average of almost 100 thousand alate queens flew from the mounds in one acre during one year. Most queens die during and after their mating flight; however, only a few queens need to survive to start new colonies. For example, if an acre is infested with 30 mounds, only 30 or 0.03% of 100,000 queens need to survive to replace the original population. Within the individual colony, large numbers of worker ants can be produced. Recent observations on colony growth within the laboratory indicate that most colonies one year or older contain at least 100 to 200 thousand workers.

Nest Site Selection

Newly-mated queens may select potential nesting sites during flight and after landing. Selection appears to be based on surface properties (e.g., moisture, soil type, topography, and reflectance). This behavior results in colonies being established in roadsides, playgrounds, shopping malls, housing developments, lawns, pastures, and some croplands. Heavily shaded areas (e.g., forests) are rarely infested.

Generation Time

Mean generation time is partly influenced by the time of year the colony is founded. However, 6- to 12-month old colonies can develop reproductive forms and stage mating swarms. With respect to mean generation times, no life tables (birth and death rates, age specific mortality) have been prepared for any IFA species on any part of their geographic range. These data are fundamentally important for sound management decisions.

Genetics

No studies have been conducted on the genetic diversity of *S. invicta* populations. If the original IFA inoculum into the U.S. was very small, there may be significantly less genetic diversity in the U.S. than in the South American population. The diversity of the U.S. population could affect the rate of spread of IFA to new habitats and the rate of evolution of resistance to various control measures.

Development

The ontogenetic development of individual ants has received some attention in the laboratory, as has the influence of some abiotic and biotic factors on the rate of development. The underlying principles of colony foundation, growth, and development are broadly known, but the role of ecological factors on the rate (i.e., the dynamics) of the process needs to be quantified.

Feeding Behavior

Because the IFA can exploit many different food sources, there are no known limits to its distribution based on feeding behavior. IFA colonies can survive considerable worker mortality because, under conditions of stress, feeding behavior is directed towards maintaining the queen. The present understanding of the dynamics of food distribution within the colony may result in the design of more effective bait formulations. Temporal changes in feeding preferences can affect management strategies where baits are used.

Endocrine Systems

Understanding the IFA endocrine system may lead to control tactics that affect colony integration and development. The endocrine system of IFA has been studied mainly from the standpoint of caste determination. Juvenile hormones play a major role in this. Juvenile hormone analogues that can severely disrupt the reproductive processes of IFA are being extensively studied as potential control agents.

Pheromones

Queen pheromones help regulate the social organization of the nest and influence reproductive potential. The queen attractant/recognition pheromone ensures that the queen is fed, groomed, and protected by her workers. This same pheromone is applied to eggs as they are laid, causing workers to care for the eggs. Queen pheromones regulate reproduction by (1) producing new queens (caste determination), (2) suppressing egg laying by virgin queens in the parental nest, and (3) causing workers to execute queens. These regulatory queen pheromones have considerable potential as control agents. Several components of the attractant/recognition pheromone have been chemically identified, and synthetic materials are currently being evaluated for biological activity.

The IFA also produce a brood pheromone and a trail pheromone. The brood pheromone elicits tending behavior by the workers to the larvae. The trail pheromone directs workers to newly-discovered food sources; some of its chemical components have been identified. These may be used to enhance the attractiveness of baits. The special advantages of using pheromones in control programs are that these naturally occurring compounds are highly specific to the IFA and should be environmentally safe.

BENEFICIAL AND DETRIMENTAL ASPECTS

Cotton

In the cotton agroecosystem, the IFA is both detrimental and beneficial. Negative effects occur from IFA stings to workers when hoeing, harvesting, or repairing equipment. The IFA is beneficial in controlling cotton pests, such as boll weevils. When four IFA's are found per ten plant terminals, boll weevils will be controlled 90% of the time. IFA are also considered to be a key predator of *Heliothis* species, such as the bollworm and the tobacco budworm. However, many natural entomophages feed on these *Heliothis* species, so if the IFA were removed, other entomophages may still maintain these pests below economically damaging levels.

Mound sampling is not an effective way to assess IFA density in a cotton field. During the early part of the growing season it may be difficult to find mounds in a field. A "beat bucket" sampler on plant terminals precisely determines the abundance of foraging worker ants and is useful when making management decisions for pests of cotton such as the boll weevil.

The IFA colonize cotton fields early in the growing season primarily in response to aphids as a source of honeydew. After colonization, the IFA tend to aggregate in the field primarily in response to aphid aggregation. The dispersion of worker ants in the cotton field is best described by a negative binomial distribution.

The IFA may kill other entomophagous arthropods. They have been observed consuming parasites of aphids and boll weevils. Although the IFA generally are thought to be effective predators on entomophagous species, other data indicate that they only minimally impact the abundance of most entomophages.

Sugarcane

Although the IFA is generally an excellent predator of the sugarcane borer in sugarcane fields, at harvest time IFA mounds may damage equipment and the ants may sting workers. Some sugarcane farmers would prefer to live without the IFA simply because of its sting. However, it is well documented that the IFA saves the sugarcane farmer an average of one to two insecticide applications per season by feeding on the sugarcane borer.

Sweet Potatoes

The IFA tend to infest entire fields of sweet potatoes, but greater numbers are found around the periphery of the fields. Since all sweet potatoes must be harvested by hand, even in highly mechanized farms, IFA create problems with the laborers in the harvesting process.

IFA prey on the egg and larvae of the banded cucumber beetle and the sweet potato weevil. When IFA are controlled, both insects and their damage increase in sweet potato fields. In fact, the statewide problem with these two pests increased immediately after large scale control measures were initiated for the IFA. More research, however, is needed to determine if this resurgence is due partly to the reduction of predators other than the IFA.

Soybeans

The IFA is considered to be a nuisance pest on soybeans, grain sorghum, and corn and may be of economic significance where ants are very abundant or where seed has not been well covered at planting. Definitive economic assessments of losses in these crops is generally not available and there is a need for additional unbiased research on the impact of IFA on these crops.

In soybean fields, IFA interfere with harvest and feed on germinating soybean seed. Large IFA mounds, particularly around the borders of soybean fields, frequently clog the cutter blade of combines. Thus, a problem is posed to the person removing the ants, dirt, and debris by hand.

IFA prey on several pests and serve as an important predator on many detrimental insects in soybean fields. Three-cornered alfalfa hoppers, stink bugs, and several lepidopterous soybean pests are reduced by IFA predation. Research in Louisiana has shown that insecticides that reduce IFA numbers actually increase the number of three-cornered alfalfa hoppers. No insecticides at this time give better than 60% control of this pest—the same control provided by IFA.

Forest

The Nantucket pine tip moth larvae are significantly reduced by the IFA. This pine pest infests pine branch tips, causing additional branching rather than the more preferred erect growth. The IFA has also been observed feeding on bark beetles in pine forests.

Pastures and Hay Fields

The IFA pose a problem with equipment in cutting hay and with bush-hogging operations of pastures. Large IFA mounds require that tractors be run at considerably less than maximum efficiency. Sickle blades and bush-hog blades are often broken as a result of the mounds. In addition, the small hay bales (60 to 100 pounds), if left on the ground overnight, attract large numbers of IFA, making it extremely uncomfortable for laborers to haul the hay. In general, IFA are considered a significant nuisance in and around hay fields and to a lesser degree in pastures.

The IFA, however, serves as an excellent predator of ticks, horn flies, and stable flies. In many areas, the IFA have reduced lone star tick populations so well that the tick is no longer considered economically important. IFA also reduces horn fly populations, but not as dramatically. Although leafhopper numbers are reduced by IFA predation, it is not known how much actual damage the leafhopper does to pastures.

Wildlife

IFA may kill young quail, rabbits, and other forms of wildlife, especially those that nest on the ground, and therefore, are more vulnerable during the early hours of life. The IFA probably are one of many native predators of these animals, as studies have not demonstrated reduced abundances of these animals due to IFA predation.

Song birds, field mice, etc., might be detrimentally affected by large numbers of IFA, but no studies document this effect.

Although the Louisiana Department of Wildlife has documented cases of both young quail and newly born rabbits being killed by IFA, they have also shown that quail numbers in the primary sugarcane producing parishes are greater now than they were in the late 1950's and early 1960's. In addition, rabbits are as abundant as they were before the IFA colonized the Florida Parish of Louisiana.

RESEARCH NEEDS

There are legitimate research needs for short-term chemical solutions to the IFA problem in particular areas and for long-term ecological management of IFA over the entire area of its distribution. We address here the biological information necessary for long-term IFA management. It is important to recognize that undue emphasis on short-term chemical solutions has two important negative consequences. First, the distribution of available funds will be disproportionately directed towards short-term solutions. Second, long-term IFA management can be more difficult due to adverse ecological consequences from an over-emphasis on chemical solutions.

RECOMMENDATIONS

1. Research the basic population dynamics of the IFA and related ant species in disturbed and non-disturbed habitats in the South American homeland and in the United States.
2. Develop life tables for IFA colonies in South and North America.
3. Assess potential biocontrol agents (parasites, predators, pathogens, and competitors) in Brazil and the United States.
4. Study the factors influencing mating flights and colony founding, particularly (a) abiotic factors influencing flight initiation, mating, and dispersal; (b) intrinsic factors influencing readiness to swarm; and (c) factors influencing nest site selection.
5. Investigate interspecific competition between IFA and other ants in vari-ous South and North American habitats. Also study interspecific competition in and on IFA populations found on the periphery of infested areas.
6. Investigate intraspecific competition among IFA colonies and the role it plays in determining population densities.
7. Investigate the intrinsic factors influencing the production of males and virgin queens.
8. Continue researching the endocrine and exocrine systems (hormones and pheromones); determine how these regulate reproduction.
9. Chemically identify pheromones, and evaluate their potential as control agents.

10. Analyze the genetic diversity (heterozygosity) of IFA in its South American homeland and in the U.S.
11. Evaluate the impact of the IFA on pests and beneficial arthropods in forest and agricultural ecosystems.
12. Determine how IFA populations effect wildlife and domestic animals.

PANEL IV

ENVIRONMENTAL TOXICOLOGY

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INTRODUCTION

Repeated failures of massive eradication programs for the imported fire ant (IFA) have focused attention on the benefits and risks of the eradication process. The environmental toxicology of the ecosystem complex where humans and the IFA compete directly with one another comprises a large part of the benefit/risk equation. The two major components are the toxicological and human health hazards resulting from infestation by the stinging IFA and the destruction of wildlife and the pollution of the human environment resulting from the widespread use of persistent organochlorine insecticides. The Panel examined these issues in some detail and has summarized these discussions in a series of reports (Appendices A through H).

IFA VENOM AND HUMAN HEALTH

The presence of IFA infestations over a 10-state area of the eastern and southern U.S., about 240 million acres (97 million ha), has brought *Solenopsis invicta* into direct conflict with an estimated 40 million inhabitants. This conflict has excruciating reality to urban and rural dwellers because of the aggressive stinging behavior of IFA. The IFA venom contains a unique series of dialkylpiperidine alkaloids together with reactive protein constituents that collectively are responsible for the urticaria and pustule formation that results from IFA stings and the hypersensitivity and allergic reactions that are experienced by perhaps one percent of those who are stung. In some cases, this allergic reaction is so severe as to require hospitalization and/or expensive desensitization treatments. Thus the presence of trillions of IFA workers from an estimated 10 billion nests over the infested area represents a readily defined and unforgettable experience in environmental biochemical toxicology. In appended reports, the panel has summarized knowledge about the fire ant venom—its generic composition and evolution (Blum 1982, Appendix A)—and has placed in perspective the medical aspects of the consequences of IFA attacks on humans (Schmid 1982, Appendix B). These appraisals together with detailed analyses from Panel I and other components of this Symposium should make it possible to characterize the human risk element of IFA infestations.

The Panel believes that a better assessment of the actual impact of fire ant stings is essential to the long term management of the fire ant problem. Such an assessment should include (1) epidemiological studies of IFA morbidity and correlations between IFA densities and incidence of morbidity, (2) toxicological studies on IFA venom (especially the diakylpiperidine alkaloids), and (3) research on the natural products of the IFA and their potential role as population regulators.

INSECTICIDES FOR IFA CONTROL

Environmental toxicology has been centrally involved in the IFA "problem" ever since organized attempts were first made to control its spread by the use of insecticidal chemicals (about 30 years). The insecticides chosen for control and later eradication efforts were the hexachlorocyclopentadiene adducts chlordane, dieldrin, heptachlor, and mirex. These insecticides can be collectively described as extremely persistent in the environment, broad spectrum in their toxic action, highly bioaccumulative with long residence times in human and animal tissues, and generally hazardous to a wide variety of terrestrial and aquatic wildlife. These insecticides have also been shown in a variety of animal experiments to be chemical carcinogens. The extensive usage of chlordane, heptachlor, and dieldrin for IFA control from 1957 to 1962 on millions of acres, produced countless problems in environmental toxicology relating to bioaccumulation in human tissues, severe damage to wildlife, and threats to human health.

The introduction of mirex baits for IFA control in 1962 represented a step forward entomologically, in that control efforts were more selective for the target pest (IFA) and dosages were dramatically reduced from about 2 pounds AI (active ingredient) per acre for heptachlor and dieldrin, to 1.7 grams and later to 0.4 grams of mirex per acre. At first, mirex was touted as being the perfect insecticide. While heptachlor and dieldrin primarily killed ants after they left the mound, mirex, a delayed stomach poison, allowed foraging workers to carry the poison back to the nests where it was transferred to the queen and nestmates.

Mirex, however, proved to be even more environmentally recalcitrant than chlordane, heptachlor, and dieldrin. Even small dosages caused serious problems in environmental toxicology of field, stream, wildlife areas, estuaries, and the human ecosystem. Mirex is one of the most stable xenobiotics known. It dissolves in water to about 20 ppb (parts per billion) and has an octanol/H_2O partition coefficient of about 10,000. Residues of mirex were found in snails, crayfish, fish, birds, turtles, vertebrates, and humans. It accumulated in the brain, muscle, liver, skin, and tissue of mammals; was resistant to metabolic attack; was not readily excreted; biomagnified; leached into soil; attacked non-target insects; and persisted in the environment. The Panel has endeavored to place these toxicological effects and their ensuing political and sociological consequences in perspective in the appended papers (Metcalf 1982, Appendix C; Hinkle 1982, Appendix D).

In 1973, EPA prohibited mirex from

being sprayed in coastal counties or broadcast on aquatic and heavily-forested areas. In 1977, mirex was phased out of use as an insecticide; Mississippi was permitted to apply mirex on mounds and ground broadcast. The pesticide registration of mirex was cancelled on June 30, 1978.

Once the environmental toxicology of mirex baits for IFA was recognized, more rational methods for insecticide use were explored. Significant progress was made in understanding the environmental degradation of mirex and characterizing the toxicological properties of the degradation products. From this information a new formulation, ferriamicide, was developed (Alley 1982, Appendix E). Ferriamicide incorporated mirex (0.05%), ferrous chloride hexahydrate (0.2%0, and soybean oil (8%) to promote more rapid photolysis and faster environmental degradation.

Field degradation studies showed that after three years, only 20% mirex was found in plots treated with a 300-fold application of ferriamicide. The added amine and ferrous chloride components were shown to reduce the half life of mirex from 12 years to about 0.15 years. Such accelerated degradation was felt to result in decreased problems with bioaccumulation and biomagnification.

The use of ferriamicide, however, also posed problems in environmental toxicology. Its principal environmental degradation product is photomirex—a highly toxic and carcinogenic product. The State of Mississippi was granted temporary registration by EPA to use ferriamicide as a mound treatment until July 30, 1978. Before a renewal was submitted, chlordecone (Kepone) was found in shelf samples of ferriamicide (Metcalf 1982, Appendix C). Chlordecone, an analogue of mirex, had been shown through the Hopewell, Virginia, episode to be highly toxic to humans and animals as a delayed neurotoxin, an estrogen, and a carcinogen.

PESTICIDE REGISTRATION

The responsibility for pesticide registration rests with the EPA whose registration guidelines require that extensive toxicological and environmental studies be conducted before registration can be granted. Detailed evaluations of these studies are made by scientists in the Office of Pesticide Programs (a division of EPA). Although under the Federal Insecticide, Fungicide and Rodenticide Act (FIFRA), registrants must demonstrate the safety of their products, ultimately, EPA bears the burden of determining the safety of a pesticide.

EPA also conducts risk assessments to determine the likely risks of pesticide use. In addition to the toxicology of the pesticide, these assessments consider human and environmental exposure, i.e. actual use practices, human activities at treated sites, and possible absorption of residues. These requirements are discussed in more detail by Severn (1982, Appendix F).

Little information has been available on the exposure of applicators or the general public to pesticides for IFA control. While methods to measure direct exposure from other types of pesticide use have been available, field measurements of exposure to bait formulations has not been conducted. As more chemicals come before EPA for registration for IFA control, such measurements will need to be conducted (Nigg 1982, Appendix G).

DEVELOPMENT OF NEW INSECTICIDES

The Panel has surveyed the range of insecticides currently registered for IFA control as well as those under immediate development. The Agricultural Chemical Industry responded wholeheartedly to our request for information on the range of properties, uses, and performance that we judged as esssential to evaluate the environmental toxicology of each insecicide, i.e.:

1) chemical name and structure,
2) chemical and physical properties, including melting point, vapor pressure, water solubility, and octanol/H_2O partition coefficient,
3) metabolic and environmental degradative fate and pathways, soil persistence, etc.,
4) acute and chronic toxicity,
5) possible mutagenicity, carcinogenicity, teratogenicity,
6) wildlife toxicity and hazard,
7) use patterns, and
8) proposed label directions.

This information is appended in data sheets dealing with (a) mound drenches, (b) bait toxicants, and (c) insect growth regulators. The properties, toxicological evaluations, and uses of all the chemicals studied by the Panel are summarized and presented in Appendix I.

As a result of this approach and thanks to the excellent cooperation of Drs. Clifford Lofgren, D. F. Williams and W. A. Banks of the USDA, we can report that there is a considerable array of insecticides that probably can be recommended and utilized with some confidence in direct application to IFA mounds by homeowners, licensed pest control operators, and local, state, and federal authorities.

Bait Toxicants

Several new insecticides have either conditional or pending registration with EPA as ingredients of IFA baits. These promise effective IFA control at dosages ranging from 1 to 10 grams per acre, are generally biodegradable, have favorable selectivity, and low hazards to wildlife. It seems probable that they will be used in a variety of

IPM efforts (see Appendix I, bait toxicants).

Insect Growth Regulators

Four "insect growth regulators" (IGR) are under development for IFA control (see Appendix I, insect growth regulators). These offer considerable promise for obliterating colonies by affecting development and reproduction. These IGR's are of very low toxicity to humans and other vertebrates and are effective at 2 to 20 grams per acre in bait formulations. These new chemicals offer opportunities for new and innovative IFA control by householders, PCO's, and governmental agencies.

In using these new chemicals for IFA management, consideration needs to be given to the range of use: direct mound treatments, broadcast (ground) bait treatments, and aerial bait applications. The array of chemicals now registered or pending registration for IFA management permits a significant choice of alternatives. However, these chemicals must be evaluated carefully for their capacity to adversely affect the environment and population dynamics of target, non-target, and other invertebrates in the IFA ecosystem. Their cost effectiveness and potential for resurgence by IFA also must be evaluated.

More than 20 years of study in the "school of hard knocks" have been expended in learning about the environmental toxicology of mirex and its distribution throughout the human environment. The magnitude of the IFA problem and the need for developing more optimal insecticidal strategies for its control and management dictates that this rate of accumulation of knowledge about environmental toxicology is woefully inadequate to deal with the development of bait programs incorporating entirely new types of toxicants and insect growth regulators. Modern systems analysis and computer technology have the simulative capacity to incorporate such parameters as IFA density, rate of application, rate of effectiveness, effects of competing organisms, chemical properties such as water solubility, partition coefficient, rates of photolysis, and biodegradability, bioaccumulation potential, etc. into predictive models that will avoid environmental mistakes or irretrievable environmental damage. Greater emphasis and research needs to be directed into the development of computer simulations for IFA management.

CONCLUSION

The historical evidence shows that simplistic control and widescale eradication programs for the IFA are ineffective. It seems that the best strategy is to develop a variety of compounds. Several improved toxicants for bait formulations now have either conditional registration or are pending registration. These substances promise effective IFA control with low hazard to wildlife. Additionally, four insect growth regulators are being developed for possible use on IFA. Perhaps these compounds can be incorporated into an integrated plan to manage the IFA.

RECOMMENDATIONS

1. An epidemiological study should be conducted of IFA morbidity in typical rural and urban situations. (A preliminary discussion with epidemiologists at the Center for Disease Control has indicated that a study is feasible.) Such a study could lead to the development of an action threshold for initiating community or areawide control programs.
2. A reliable correlation should be established between IFA densities and incidence of morbidity in a variety of ecological situations. There is still a great deal of uncertainty about the pharmacological and physiological effects of IFA effects and IFA stings.
3. Toxicological studies should be undertaken on the properties of the dialkylpiperidine alkaloids in IFA venom.
4. Research should be conducted on the chemistry of IFA natural products and their potential role as population regulators. Toxicological studies on these compounds should be implemented simultaneously.
5. The cost effectiveness, environmental impact, and potential for IFA resurgence under the various control options should be considered. Using all chemicals against the IFA may have extrinsic and intrinsic effects on other ant species and on a variety of non-target species in the treatment area.
6. New insecticides and insect growth regulators should be evaluated for their capacity to adversely affect the environmental toxicology and population dynamics of the complex of target and non-target insects and other vertebrates. Particular attention should be given to the potential for IFA resurgence
7. Computer simulations need to be developed for IFA pest management methods (Wood 1982, Appendix H). Realistic models dealing with the environmental toxicology of IFA abatement procedures can be expanded into overall IFA mangement and decision-making models by incorporating such key features and technologies as:
   a) new pesticide formulation effectiveness,
   b) local area applications mapping,
   c) local area environmental effects,
   d) site specific and aggregated application costs,
   e) aggregate area benefit assessments,

f) interactive information and situation displays, and
g) distributed information system demonstrations.

PANEL V

MANAGEMENT OF ESTABLISHED VS. INTRODUCED PESTS

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INTRODUCTION

There are literally thousands of exotic pest species that could thrive in the United States. Likewise, many species already existing in this country could extend their range if transported into areas with compatible environmental parameters. Typical examples of such introductions are the movement of the pink bollworm into Arizona and California cotton production areas, the anticipated westward movement of the IFA, and the gypsy moth. Introductions of fruit fly species from foreign sources can be expected to occur periodically. These examples typify introductions that can be expected to occur with a host of species with potentially serious problems resulting. Authorities must remain alert to such potential introductions and prevent them if possible. The rapid transportation provided by jet aircraft and the enormous numbers of people travelling have vastly complicated existing quarantine systems. Quarantines are the first line of defense against introduction, and their degree of effectiveness should be continually evaluated and strengthened.

The importance of early detection of introduced pest populations cannot be overemphasized. Detection before such populations adapt to their new environment or prior to population explosion makes the problem of coping with them much simpler. Eradication, for example, may be feasible if detection is early, but eradication may be impossible at a later time. Improved detection methods should be sought continually and adopted when appropriate. Survey and monitoring techniques should be simple, relatively inexpensive, and effective. Programs to provide early detection are operating; however, their effectiveness is less than desirable and enhancement is clearly needed.

[Appendices M through P provide detailed information on the concept and practice of eradication and prerequisites (Appendix M: Smith); biological control, an historic overview and as it is applied to the IFA (Appendix N: Gilstrap); examples of eradication programs and the population dynamics of introduced species (Appendix O: Kogan); and the special problems of introduced species in urban environments (Appendix P: Frankie et al.).]

INTRODUCED PESTS IN ESTABLISHED ECOSYSTEMS

Despite the large numbers of potential pests confiscated at quarantine points, pest species continue to invade and become established in the U.S. Often these pests cause major losses to agricultural production. They also can detrimentally affect environmental quality, human health, and the aesthetic value of plants. Losses from these pests are sometimes catastrophic, and yet attempts to cope with such acute problems frequently result in ecological upsets and associated problems.

Human commerce has magnified the flow of arthropods across geographic barriers. Although measurement of the rates of movement in terms of numbers of species and of individuals per species is difficult, APHIS reports on interceptions may be a valuable data base for an analysis of these events. (For example, in a one-year period (1978 to 1979), 14,002 insect plant pests were intercepted at quarantine points.) Some species that cross geographic barriers successfully establish themselves in a region. Many more species do not succeed probably due to hazards in the new region, such as (1) the absence of adequate hosts, (2) inhospitable climatic conditions, (3) predation by general native predators, and (4) genetic degeneration due to excessive inbreeding because of the narrow gene pool of the few colonizers.

Agricultural Environments

Many introduced pests have been detected approximately 10 to 15 years after the presumed date of immigration. After this initial, latent phase, the pest population, free of effective natural enemies and better adapted to the new environmental conditions, explodes. It is in the beginning of the explosive phase that the pest most often is detected and control actions are contemplated. During the explosive phase, IPM programs in agricultural ecosystems are disrupted, because researchers, extension specialists, the pesticide industry, and producers must redirect their efforts, thus hindering long-term programs (see Appendix N).

Many introduced species that go through this explosive phase are extremely difficult to eradicate. They expand their geographic range and, after a time, stabilize and are increasingly affected by the regulating forces of the new environment. Sometimes the stabilized population exceeds tolerable levels. Such introduced pests often become key pests of a crop, either as an additional key pest, by replacing previously-established key pests, or by assuming key pest status if the crop was previously free of key pests. This status means that inadequate population regulation exists and control procedures must be applied on a recurrent basis. Often this disrupts other pest populations that were previously under dynamic equilibrium and kept in check by natural enemies. The boll weevil in cotton is a classic example and dramatically illustrates this phenomenon. Among the many consequences of the boll weevil invasion many years ago has been the rise of *Heliothis* to its current position of prominence in cotton ecosystems throughout the cotton belt, largely because attempts to control the boll weevil, mainly with insecticides, have so destroyed the natural biotic components in the cotton environment that *Heliothis* populations are released from effective population regulation.

Public awareness of newly-introduced pests usually occurs during the explosive phase of establishment. The public often overreacts, even panics, and pressures authorities to "act." If the energies of the public outcry are directed correctly, they may help generate the necessary funds to support the coordinated efforts that are required to eradicate, contain, or manage the pest, e.g. the imported crucifer weevil in Illinois.

The examples of the European corn borer, cereal leaf beetle, and several other introduced agricultural pests suggest that it is virtually impossible to detect these pests during the early phase of establishment. Quite possibly, this difficulty is one of the reasons why the eradication programs for these pests failed.

Urban Environments

In contrast to agricultural environments, new pests introduced into urban environments often exploit previously unoccupied niches, mostly because so many actual and potential niches are extant in urban areas. This in turn is related to the urbanization process, which includes the introduction of a wide variety of exotic plant species and the establishment of new structures and the renovation of old ones. Thus, one may expect most newly-introduced species to occur in urban environments. In some cases, these pests establish in indoor habitats that are geographically far beyond their usual physiological limits (e.g., pests that invade indoor habitats in cold climates).

Because many species introduced into the urban environment cause aesthetic rather than economic loss, they may be assimilated with little overall impact on urbanites (witness the introduction of a new domiciliary cockroach species or a new aphid species on an ornamental plant—organisms that are already represented in most urban areas). On the other hand, when the introduced species are considered to be of economic or public health importance, the impact may be substantial, especially from a social standpoint.

Frankie et al. (Appendix O) postulates that urban centers are and will remain the areas of first discovery for most exotic pests, mainly because urban areas are the major points of entry for goods and people by air or sea. Once new pests are established, people may exacerbate their pest problems through their everyday activities, for example, through their intra- and intercity movements where they unknowingly transport pests to uninfested areas (i.e. gypsy moths, IFA, bark beetles, Dutch Elm disease, Japanese beetles). In fact, such activity could be the route of first introduction. Once arrived, pests may interact with people and essentially become more of a "people problem" than a strict biological problem due to the way people perceive and respond to these pests.

People can further increase their pest problems when they muster enough political power to determine or greatly influence the type of control programs to be used against the pests. Often these are not the most effective programs and thus represent compromises that are strongly tempered by social and political considerations. Results usually are unnecessarily expensive and environmentally detrimental. Some urbanites cooperate in management programs, but many are apathetic. This may be related to the aesthetic nature of the problem rather than to economic or public health concerns.

Other Environments

Newly-introduced pests can economically impact animal production. In the 1880's, the horn fly spread throughout the country; control costs and economic losses due to reduced animal production were great. The screwworm, native to the southwest U.S. and introduced into southeast U.S. in the 1930's, annually caused losses and control costs in the millions of dollars, until it was essentially eliminated. The face fly, another economically important introduction, also affected animal production. These types of introductions have impact because of the insect itself. Introductions of diseases present a different problem. For example, the mosquito, *Aedes aegypti*, although a very old introduction, exists and is a potential vector of dengue fever which is currently present in the Caribbean area and Mexico. Other diseases of humans and animals could be introduced because the vectors of these diseases are present in the U.S.

MANAGEMENT METHODS FOR INTRODUCED PESTS

Research Needs

There is an historic and substantial gap between the "action" of regulatory agencies charged with conducting eradication programs and research scientists who have generated the information and technology used for various control tactics. This point was made extremely well by W. L. Brown, Jr., who over 20 years ago reviewed four, area-wide, mass insect control programs, of which one was the IFA. Brown (1961) was highly critical of the programs because research was not integrally involved.

> Every mass control campaign should have an adequate research program functioning as far ahead as possible before control operations get underway. The control work should be guided by the research and not the reverse, and every campaign should be reevaluated frequently to see if a need for it continues.

The newly-detected, introduced pest presents a rather unique set of problems. Not only must decisions be made quickly regarding tactics and scope of the program, but these decisions are usually based on limited biological information and no certainty of the pest's rate of success or distributional increase in the new environment. Furthermore, recent decisions, made by a small group of state and/or federal regulatory personnel, have often opted for eradication via pesticide application. Eradication programs are not always successful, and when they are not, research to develop or implement alternative courses of action is generally inadequately organized or funded. This delay in research activity is unnecessary and unwise, as area-wide programs are increasingly subject to public focus and participation. Such public focus should be used to initiate research into short and long term needs and studies on alternative management tactics.

The short-term management research needs could include advice from a panel of appropriate scientists regarding pesticide options, formulations, modes and rates of application, and, perhaps most importantly, obtaining and interpreting efficacy data. The short-term research panel would also promote collection and interpretation of literature; considerations regarding best methods and materials for detection; and suggestions for kinds of approaches to, and suitable scientists for, pressing research needs. Short-term management research should also continually evaluate program objectives and actions. The formal incorporation of research in an advisory role to eradication programs (1) would be relatively inexpensive, (2) would allow early development of research needs on a commodity and area-wide basis, (3) should substantially improve prospects for successful eradication, and (4) would assure the affected public of an organized transition into other management tactics.

Given that an eradication program evolves into one only of containment, the original short-term advisory panel should become involved in developing the probable changes in longer-term tactics for regular commodity protection (e.g., changes in recommendations for IPM) and production. These changes would minimize the immediate impact of the pest on affected crops and existing IPM programs. The panel should recommend and promote new research needs where required to develop potential crop protection options.

Biological Control

Classical biological control is more likely to succeed for introduced pests, and can permanently regulate populations. Because of this, preliminary studies on biological control, possibly funded by the eradication program, should be initiated at an early date and should be evaluated in the event eradication cannot be undertaken or fails. These studies should be separate from objectives of the short-term research panel and should function concurrent with early eradication attempts. The research panel should include a taxonomist of parasitic Hymenoptera and/or Diptera as appropriate, an insect pathologist, a quantitative ecologist, and a specialist with formal training and experience in classical biological control. Initially the panel would evaluate the prospects for successful biological control, including (1) known natural enemies and their biologies and distribution, (2) probable host plants and any existing host-plant resistance of the pest in the aboriginal home, (3) potential foreign exploration problems and needs, and (4) the ecosystem of the pest in the aboriginal home.

The panel's role and activities would increase if the eradication program looked like it was failing. Foreign studies would be initiated to begin collecting and testing the pest's natural enemies. If the eradication definitely was not working, funding would shift to biological control and eradication tactics towards containment using control methods compatible with establishing new natural enemies.

Eradication

The term "eradication" as used here means to eliminate a pest population from a specified area. Presumably, having eliminated the pest population, the area would remain free of the pest until reentry by mobility of the species or introduction through human activity. Ecologically, eradication involves removing a species from a niche. This action sometimes opens the niche to one or more other species that may be economically significant. As eradication is normally directed against newly-introduced species, the steps involved in pest establishment and stabilization are of particular interest. The population dynamics of newly-introduced species usually reflect three phases: (Phase 1) establishment in the niche, (Phase 2) rapid population growth, and (Phase 3) stabilization from the actions of biological constraints.

During phase 1, pests are most vulnerable to eradication efforts; therefore, early detection is necessary. Once the introduced pest advances to phases 2 and 3, its uniqueness and vulnerability changes and becomes similar to the problem posed by indigenous pests.

Biology, economics, and politics influence eradication. The political factors are particularly complex because they involve different constituencies and political entities and agencies having conflicting objectives and needs. The case histories of eradication programs are widely variable, ranging from highly effective programs to abject failures. Based on experience acquired over a period dating from the earliest eradication programs in the late 1800's, a list of prerequisites needed for programs to have a reasonable probability for success can be drawn. This list includes the following:

1. High socioeconomic importance of the pest. The eradication strategy generally, but not always, involves a comprehensive research program to develop the needed technology. This phase is followed by a complex phase involving extensive control programs. Such major effort should be reserved for insect pests of high socioeconomic importance.

2. Specific advantages of eradication over suppression. Unless there is a clear advantage to eradication over suppression, eradication is not justified assuming effective technology and modest economic and environmental costs for suppression programs. Recent advances in controlling cotton pests, for example, requires a reassessment of the eradication option.

3. Effective monitoring technology. Effective technology for monitoring pest populations must be available. Without such technology, it is impossible to determine the area infested by the pest or the results of treatment. Recent advances in pheromone chemistry and technology offer promise here.

4. Effective control technology. In most cases, eradication efforts will involve a combination of measures. The potential effectiveness of the total effort must be demonstrated before undertaking eradication, particularly in large expensive programs. This poses special problems because of the difficulty of interpolating from small, preliminary tests to large area tests. The paucity of data on effectiveness of IFA treatments, for example, was a problem of early eradication efforts.

5. Environmentally acceptable programs. The impact of control programs on the environment must be assessed before launching eradication programs. This poses a difficult problem because of the time element involved in making preliminary determinations.

6. Favorable logistical odds. Large-scale application programs should be simple or the element of human error is likely to cause serious setbacks. The accuracy of aerial application or the thoroughness of scouting for infested areas are the kinds of operations alluded to here. The likelihood of failure increases as the size of the infested area increases. Similarly, the longer the pest has been established, the better it adapts

to its environment.

7. Adequate funding to sustain programs. Realistic estimates of costs often have not been established before programs are begun. Undertaking programs that have open-ended budgets will likely place the program in jeopardy as funding may be dropped or credibility may be lost because of excessive costs. The WHO program on malaria eradication illustrates the impact of inadequate funding, although other major flaws existed in the overall design.

8. Adequate administrative resources to sustain programs. A high level of administrative competence is required to coordinate an eradication program. This essential input is more difficult to provide when programs extend across state and national boundaries. Good science and sound scientific advice should be the foundation for administrative decisions early in the planning period.

9. Favorable socioecological conditions. The success of eradication programs may depend on the cooperation and active participation of area residents. It is essential that a high level of public support is assured so that regulatory authority can be invoked to take required measures with minimal impediments.

10. Favorable cost/benefit relationships. The great appeal to eradication programs is that through the initial "capital investment" phase the pests will be eliminated thereby avoiding the recurring costs of control programs. These cost/benefit relationships must be calculated realistically to avoid disillusionment.

No list of prerequisites can assure success of eradication programs. An element of risk will always remain. Eradication should be a viable option subject to rigorous assessments to determine its appropriateness. The ten points listed above should help in putting this decision-making process on a scientific basis and in improving biological, social, environmental, and economical acceptance.

RECOMMENDATIONS

1. Each new eradication program should include concurrent research to identify the pest's probable aboriginal home; the existing biological restraints, particularly the existence and taxonomy of potential natural enemies; the known host plants; and the political mechanisms needed in the foreign country to implement programs.
2. The program ideally should consist of a taxonomist specialized in the pest group, a taxonomist of parasitic Hymenoptera and/or Diptera as appropriate, an insect pathologist, a quantitative ecologist, and a specialist with formal training in biolo-

gical control.

3. The following considerations should be made to guide decisions on large eradication programs:

   Assess and demonstrate the effectiveness of eradication tactics;

   Assess the socioeconomic importance of the pest;

   Evaluate the advantages of eradication over other control strategies;

   Determine the availability of effective monitoring systems;

   Develop concurrently effective control technologies;

   Assess environmental acceptability of the program;

   Assess the availability of favorable logistical odds;

   Assure availability of adequate funding to sustain such programs;

   Assure availability of adequate administrative resources to sustain the program;

   Assure adequate communication with the public affected by the program;

   Evaluate the probability of a favorable cost/benefit relation of the program.

4. The effectiveness of existing quarantine and inspection procedures (international and between states) that deal with movement of travelers and products be evaluated. Effectiveness needs to be enhanced wherever possible, including new educational materials that notify departing travelers of kinds of items restricted on re-entry and the rationale behind such restrictions.

5. Appropriate educational materials should be prepared for informing the public, particularly in the vicinity of ports of exit and entry, about the identification, biology and importance of introduced pests. This information should be available to urban and non-urban residents.

6. Aggressive efforts should be made by responsible and informed officers to prepare and deliver education materials to the public and public officials explaining the importance of introduced pests and why efforts to manage them, although an inconvenience, are imperative.

7. Students should be given information on the importance of introduced pest problems and in the philosophies, methodologies, and need for eradication as one option to cope with such problems.

PANEL VI

IFA MANAGEMENT STRATEGIES

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INTRODUCTION

Evidence shows that the red imported fire ant, *Solenopsis invicta*, cannot be eradicated from the U.S.; therefore, there will be a continuing need for programs to manage this pest. The actual pest status of the imported fire ant (IFA) is yet undetermined; however, the fact that it is a pest is irrefutable, although much more needs to be known about its public health, economic, and nuisance impact in various environments. The IFA is a human or "people" pest of major medical importance. Surveys show that 25 to 30% of the persons living in infested areas are stung at least once each year (Clemmer and Serfling 1975, Adams and Lofgren 1981, Yeager 1978). Less well-defined data suggest that up to 1% of the persons stung may require medical consultations (Lofgren and Adams 1982). A survey by physicians in Jacksonville, Florida, estimated that 3.8 new persons per 100,000 population develop a hypersensitivity reaction each year (Rhoades et al. 1977). This figure translates to about 1,500 new cases per year over the IFA-infested area. Its importance as a pest of pastures, livestock, and crops is less defined. Although the possibility of crop losses exists, especially in soybeans, the IFA has been shown to be a beneficial predator in several agricultural ecosystems (Oliver et al. 1979).

The problem of controlling the IFA is particularly difficult because the ant occupies a wide range of habitats and is an extremely effective colonizing species. Primary objectives of any management program for IFA are to maintain the species at a density level low enough to reduce its (1) public health impact by minimizing contact with humans and (2) impact on farming operations and crop production. Fulfilling these objectives requires strong suppression of IFA in areas where there is a high probability of human-ant contact and maintenance of IFA populations in other areas at levels that do not cause nuisance or economic problems.

As the only available tactic for strong temporary suppression of IFA, chemical controls (see Appendix K) will have to be used periodically (usually once a year) to eliminate new or re-infestations. Biological or cultural controls are desirable; however, no biocontrol techniques are available and probably will not be for at least five to ten years. Emphasis needs to be placed on research to discover biological and other non-chemical approaches to control. The most desirable long-range strategy for any IFA management program should be a combination of chemical and non-chemical controls where IFA cannot be tolerated and biological controls or integrated pest management where low-level populations can be tolerated.

In some habitats the IFA is a key beneficial insect. In Louisiana sugarcane fields, the IFA is the most important beneficial of the biological control component which reduces sugarcane borer populations by 25% (Reagan 1982). It is also an important predator in Louisiana soybean fields (Stam 1978). The IFA has drastically reduced tick populations in Louisiana and has been associated with a decline in tularemia disease (Burns and Melancon 1977, Oliver et al. 1979). The IFA also preys on horn flies and other pests in pastures (Howard and Oliver 1978 & 1979). However, the IFA also tend disease-carrying aphids and kill ground-nesting bees (Vinson, unpublished).

CURRENT TECHNOLOGY USE IN VARIOUS HABITATS

The IFA occupies a variety of habitats in urban, suburban, and rural situations. The pest status of the IFA in each of these habitats differs because the ant causes varying types and degrees of problems and, in a few cases, is beneficial. Because of these disparities, certain questions must be considered for each habitat where control is needed:

1. What is the nature and magnitude of the problem?
2. What measures are available to solve the problem?
3. Who makes the decision to take action and what action should be taken?
4. Who implements the action?

These questions imply that the decision-maker will bear the cost of the action.

Homes: Urban and Rural

Generally, the problem in this habitat is human exposure, especially that of small children and hypersensitive individuals, but it may also include aesthetic appearance of lawn and garden. The tolerance for either problem is likely to be very low, with treatment costs probably not a determining factor.

Several pesticides are labeled for homeowner use as mound drenches; one is labeled as a bait for mound or broadcast treatment (see Appendix K). In addition, homeowners can drench mounds with hot water if only a few to several mounds are to be controlled; however, this method is minimally effective and requires multiple applications.

Ultimately, the decision to treat rests with the homeowner or occupant, if a lessee or renter has authority to make such decisions for the owner. If control action is decided on, the responsible person has the freedom, because of the availability of materials registered for home use, to implement the action or to hire a pest control operator or other agent. In some instances, government control programs are necessary to give relief to homeowners on limited incomes.

Public and Private Lands

Because the accessibility and activities in these areas makes contact with the IFA highly probable, human exposure is generally the main problem and, perhaps, aesthetics. Sites of concern include school grounds, play grounds, parks, cemeteries, median strips or borders of streets and roads, municipal golf courses, power line rights-of-way and easements, grounds of municipal facilities of one type or another, rest areas, levees, etc. In the case of levees, tunneling by the IFA could cause water seepage. In contrast to homesites, public exposure includes children in schools, citizens utilizing recreational and other areas, and employees of various organizations having stewardship over the land. Questions of legal liability of the respective controlling authority for harm to persons by IFA stings may arise and could be a factor in determining tolerance levels.

All of the EPA-approved control measures available to the homeowner are available for public lands. If large areas are involved (more than a few acres), individual mound treatments with drenches are impractical; however, baits may be used either as individual mound treatments or broadcast with ground or aerial equipment.

In every case cited above, some identifiable agent has stewardship and authority over the land concerned. School boards, park boards, county boards, city councils, for example, generally make decisions on the management of the land within their commission—including pest control decisions. Decisions may be based on concerns of the patrons; therefore, the tolerance for IFA may vary with each case. There may, for example, be a much lower tolerance set for IFA on school playgrounds than for IFA in median strips. Legal liability may be another factor affecting tolerance levels. In any event, the decision to take action will be jointly considered by the legally-accountable authorities, if not also by the patrons. The decision may be tempered by the availability of funds to support the action (e.g., the tolerance threshold may be partly determined by the cost of treatments). This is more likely to be an issue on public lands than on homesites.

Depending on fiscal, manpower, and equipment resources of the agency concerned, a control measure may be implemented by the agency, or contracted through commercial operators. Private golf courses constitute a special case. Usually, however, golf courses have professional managers authorized to take the necessary action to control IFA, or at least to seek approval to do so from the governing board or other governing body of the course. IFA management falls under the course pest management program which usually exists at some level of dependency on the resources and standards of the particular course. Managers generally have ready access to current pest control information through university extension, USDA, or research sources or from commercial consultants or industry.

Agricultural Environments

The most significant problem when IFA inhabit agricultural environments involves human exposure—the nuisance, discomfort, and potential health hazard associated with the ants and their sting. Potential problems exist with damage to harvesting equipment by IFA mounds and the impact on crop yields. Some data reveal that stands and yield of soybeans may be substantially reduced by IFA (Lofgren and Adams 1981, Adams and Lofgren 1982, Apperson and Powell 1982). Conversely, the literature reports that IFA are good predators, especially against the sugarcane borer (Reagan et al. 1982).

Currently, few alternatives are available to control IFA in agricultural environments. Amdro® bait is registered for application to pastures, range grass, lawns, turf, and nonagricultural lands, and may be available for cropland in 1983. On small acreage or in light infestations, Amdro can be applied to individual mounds. Another option includes broadcast treatment with ground equipment—a procedure more adapted to intermediate-size parcels of land. Aerial application is perhaps best suited for large acreages. For long-term control, yearly applications may be required. Some mechanical options, such as mound leveling in the winter, provide limited mound reduction and ant suppression.

The landowner/attendant should be the primary person in assessing the problem and selecting a course of action. This does not assume that various governmental units may or may not take the responsibility for area suppression programs when acceptable management tools and technology are available.

Regulatory Control/Quarantine

Artificial spread or movement of the IFA into non-infested areas of the U.S. through interstate shipment of items such as grass sod and nursery plants is well documented. Federal Quarantine 301-81, invoked May 6, 1958, was designed to prevent this occurrence. Initially dieldrin and heptachlor were used as insecticidal treatments to certify movement of regulated articles. Use of these products was discontinued February 13, 1970, in preference to chlordane. Chlordane was used until December 31, 1979, when the final cancellation order concerning use of chlorinated hydrocarbon insecticides for IFA quarantine treatments became effective. Currently available chemicals do not fulfill all of the necessary requirements for good quarantine treatments.

Dursban Fa-5 is registered to treat potting soils where plants are grown. However, due to phytotoxicity problems, Dow Chemical (the registrant) voluntarily withdrew this product from the market. Dursban 4E and 2E are registered as a root-dip treatment for balled and burlapped plants, but this procedure is highly disfavored by growers due to the cost and labor required for implementation. Currently, no chemical treatments are registered to treat grass sod.

Statutory authority promulgated under two Acts of Congress (Plant Quarantine Act of August 20, 1912, and Organic Act of the Department of Agriculture September 21, 1944) designate the U.S. Department of Agriculture, Animal and Plant Health Inspection Service, Plant Protection and Quarantine as the responsible organization to issue regulations governing movement of articles capable of spreading the IFA.

Growers implement USDA/APHIS/PPQ-approved treatments as specified in administratively approved control manuals (805-25.000). These treatments are supervised by federal (or in some cases state) quarantine inspectors.

Other

In addition to the above problems, IFA increasingly are reported as damaging air conditioners, water well relays, ground electric transformers, telephone junction boxes, airport lights, and underground sprinklers. This has caused inconveniences and economic losses to various commercial businesses. At this time, other than heptachlor 5% granular for IFA in telephone junction boxes, there are no controls specifically for this situation other than to use the chemicals available for control in the habitats where these types of equipment are found. Research is needed on why electrical wiring, relays, and related equipment attracts IFA and causes them to feed on and damage these items.

CURRENT TECHNOLOGY AND GAPS IN CURRENT RESEARCH

Existing, But Unavailable Tools

Several chemicals presently exist but are not available, at least for some uses, as IFA control tools for the following reasons:

Amdro is presently registered for use in pastures, rangeland, and non-agricultural areas. American Cyanamid, the registrant, has requested EPA approval for use of this product on all croplands. Data supporting use of this expanded label has been submitted to EPA (May 1982). The EPA is presently evaluating this data.

Mirex was previously used in IFA control programs. When problems of persistence, bioaccumulation, and alleged carcinogenicity surfaced, EPA cancelled all registrations effective June 30, 1978.

Ferriamicide is presently under consideration by the EPA for registration for IFA control. Questions concerning the human and environmental impact of this compound have been addressed under Panel IV of this symposium. Final determination on registration will be made by the EPA.

Chlordane was previously used in IFA control programs and in regulatory treatments. Studies alleging that chlordane was a carcinogen resulted in cancellation of most uses by the EPA on March 6, 1978. Use of chlordane for regulatory treatments was phased out December 31, 1979.

Dursban (chlorphyrifos) was previously registered as a quarantine treatment to nursery potting media and bench soils. However, phytotoxicity problems resulted in voluntary withdrawal by Dow Chemical Company pending further research to develop a dose rate that would alleviate phytotoxicity.

Lindane is currently under investigation for broad spectrum quarantine treatment. Preliminary data indicate that it will be satisfactory as a potting soil and root dip treatment. Results on grass, sod and field-grown ornamentals are incomplete.

Aldrin, which is presently registered for termite control, can be used as a root dip treatment for IFA control; however, no products are presently labeled for this use. When aldrin/dieldrin was cancelled in 1974, one of the exempted uses was the dipping of roots and tops of non-food plants. USDA indicates that this procedure (root dip) is not widely accepted by growers due to the cost and labor required for implementation.

Pesticides registered for other uses are presently pending EPA approval for IFA control. These chemicals are targeted mainly for individual mound treatments and are to be used primarily on non-agricultural lands by professionals and homeowners. The present group includes: methyl chloroform (1,1,1-trichloroethane), Imidan, Resmethrin, rotenone, lindane and Methylenebis (thiocyanate).

Current technology

1. Chemical Control

Bait Toxicants: The USDA has screened approximately 7,500 chemicals and formulations as toxic bait for the IFA (Williamson 1982). These tests are designed to select chemicals that have a delayed toxic reaction, i.e., allow worker ants to distribute the bait to other workers and the queen. Only two compounds have been registered by EPA, but registration of the most effective chemical (mirex) was withdrawn in December, 1977. In August of 1980, Amdro was conditionally registered for public use by EPA for mound or broadcast application to non-agricultural lands, lawns, turf, pastures, and range grass. Another active toxicant is being developed by the Eli Lilly Company and may have conditional registration in 1983. A third compound that acts as a toxicant and reproductive inhibitor is being developed by Merck and Company and is undergoing field tests under an EUP.

Evaluation of insecticides for use as mound drenches or fumigants to control IFA colonies has accelerated during the past few years. Several chemicals have been registered for this purpose (diazinon, chlorpyrifos, carbaryl, acephate, bendiocarb, pyrethrins I and II, and methyl bromide) and others are being tested. The problems with mound drenches are (1) the difficulty in locating small or hidden mounds, (2) the need for multiple applications, and (3) the necessity of applying the drench when the ants are most susceptible. In addition, this method of fire ant control is applicable only to very limited areas, urban properties, and homesites. Research on the factors and/or procedures needed to enhance this method of control are needed.

Insect Growth Regulators: Research on insect growth regulators (IGR) has been conducted at Texas A&M University and the USDA (Banks 1982). Most interest has been expressed in the juvenile hormone mimics, although some research has been conducted on an experimental chitin-inhibitor. Juvenile hormone mimics stop development of immature stages or induce caste shifts that result in the development of large numbers of abnormal sexuals.

A bait containing one of these compounds (Stauffer MV-678) has been field tested in a soybean oil, pregel, defatted corn-grit bait similar to Amdro. High concentrations of the compound were used to completely flood the crops of the ants. With this approach, a one-time feeding produced effects on the colony that lasted up to a year; with MV-678, 75% of treated laboratory colonies died. A field test with a bait application of MV-678 at four grams per acre was conducted at Ft. Stewart, Georgia. Applications were made in the fall and the spring. Three months after the second application, 75 to 80% of the colonies were dead, and almost all remaining colonies were without brood.

Two other insect growth regulators (MAAG agrochemical R013-5223 and Montedison JH 286) are being field tested. Problems may result from the need for several applications to provide adequate control and a lack of specificity to IFA.

Behavioral Chemicals: Behavioral chemicals (pheromones) are a fruitful area of research since a complex of pheromones regulate colony activity. Behavioral chemicals offer unique opportunities to disrupt the IFA's social organization or affect their behavior in ways that could lead to their demise. Behavioral chemicals are important in colony recognition, colony founding, egg laying, queen recognition, queen acceptance or tolerance, brood care, food and nest location, and caste control. Five pheromones are under study or have been isolated and identified (a brood pheromone, trail and recruitment pheromone, feeding stimulant, a queen recognition pheromone, and a queen dealation-inhibition pheromone). The trail, queen, brood, and recognition pheromones could be used to make toxic baits more attractive and specific.

Delivery Systems (Formulations and Application Methods): Methods for formulating baits for IFA were described several years ago and are extremely efficient. However, they must be made more specific to the IFA. One approach, other than behavioral chemicals, is a bait that would allow the use of more rapidly acting chemicals. Research is needed (1) to identify other food materials (proteins or carbohydrates) that would deliver more specific distribution of bait and toxicant within the colony, and (2) to discover if bait attractiveness is influenced by the time of year and changing food preferences of the IFA.

Methods for applying baits and other agents in large plot tests have been studied by APHIS personnel. Although delivery systems for granular baits are available for ground and aerial application, the technology needs to be further developed for more efficient and effective application. If biological control agents are found, specific delivery systems will have to be developed to disperse these agents in the environment.

2. Biological Control

Pathogens: The search for potential IFA pathogens was accelerated by the discovery in the early 1970's of a protozoan infection in fire ants in Brazil. This organism was found in up to 25% of the colonies examined, although the degree of infection varied considerably. One other microsporidian has been detected. Little is known about the epizootiology of either of these organisms. At least one bacterial pathogen and one virus have been found in *Solenopsis* in Brazil. Because no research station has been established in South America, the full potential of pathogens for IFA control cannot be assessed at this time. Research on pathogens of the native fire ant, *S. geminata*, is being used to develop methods and procedures for working with diseases of ants.

Parasites: The most highly studied parasite of the fire ants is the workerless social ant, *Solenopsis daguerri*. This ant has been found attacking colonies of *S. richteri*, but not *S. invicta*. Researchers who have worked with this social parasite conclude that it would not be useful for controlling or reducing IFA populations in the U.S. This is based on the limited distribution of the parasites in South America and the difficulty in transporting the parasites from one site to another. Species of two other groups of parasitic insects, chalcid wasps and phorid flies, are associated with fire ants. Non-specific parasites such as the nematode, *Neoplectana carpocapsoe*, are under study for treatment of individual colonies. An up-to-date review of the status of biological control of IFA is presented by Jouvenaz et al. (1981).

3. Procurement, Screening and Evaluation

Developing biological control agents is a difficult and time-consuming process. This is particularly true of pathogens. The biggest drawback to progress in this field has been the lack of a research station in Brazil from which researchers could search for biological control agents. Up to this time, knowledge has been gained through short-term trips that have lasted from two to six weeks, which does not provide time for intensive survey of any particular area and certainly has not allowed time to determine the potential usefulness of any of the organisms that have been detected thus far. Once money is available to establish a biological control station in South America, then the process of procurement, screening, and evaluation of potential agents can proceed. Provisions, however, must be made for backup resources within the U.S. for basic research on the organisms that are found and for evaluating any potential detrimental effects of these organisms to our native fauna and flora.

Physical and Cultural Control

1. Tillage and Cultivation Practices

It has been thought that tillage or cultivation deterred the establishment of IFA colonies. More recent observations, however, question this conclusion, particularly where these disturbances are discontinued. For example, IFA commonly are found in soybean fields at densities of 30 to 40 mounds per acre (Lofgren and Adams 1981). Studies in sugarcane have demonstrated higher ant populations where fields that had a dense growth of broadleaved weeds shading the roads were cultivated four times rather than the minimum two times (White 1980). However, thorough weed suppression in sugarcane possibly restricts general insect populations (potential IFA food supply) and results in up to a 50% seasonal abundance of IFA mounds (Reagan 1982). The use of hay-stacking equipment is a cultural practice change that, in effect, reduces the pest status of the IFA by reducing worker exposure in hay harvesting operations.

2. Other Mechanical Disturbances

The idea that IFA colonies can be destroyed simply by digging up or disrupting mounds has been disputed in extensive research by Blust et al. (1982). In pastures, dragging or knocking down the tumulus of the mounds during the winter resulted in greater than 50% season-long control, but only when the dragging was conducted just prior to the occurrence of freezing temperatures. Dragging at other times seems to result only in reducing mound size and thus reduces interference with haymowing equipment (Blust et al. 1982).

3. Flooding and Control Burns

Flooding does not destroy or kill IFA colonies. No information is available, however, on the effects of flooding for varying periods of time on the density of IFA colonies.

Controlled burns have not been shown to negatively affect IFA populations. Recent studies by the USDA in sugarcane fields near Lake Okeechobee, Florida, have shown that burns at harvest time may have more effect on other species of ants than on IFA. The IFA apparently escape the fire by moving deep into their mounds.

Pest Management—Research Needs

Ultimately, a pest management program needs to be developed for the IFA. Such a program must be based on sound, biological and ecological knowledge of the ant as well as sound, economic and sociological information. Economic thresholds, nuisance thresholds, cost/benefit ratios, beneficial effects, and environmental and other external costs must all be accounted for. At present, very little of the information and technology needed for a pest management program (as opposed to single control efforts) are available. A pest management program on the scale needed for the IFA would require an institutional framework capable of integrating information and making decisions. Such a framework also would aid in allocating funds into necessary research.

Figure 1 is a prototype management support system. Data from the ecosystem, obtained via monitoring, are recorded and evaluated such that decisions can be made in designing management systems. As management schemes are implemented in ecosystems, they are monitored, and the support cycle continues. In such a system, communications are vital: the public needs to be informed; staff must know what is going on and must have input into decisions; and peer review of research must be maintained. Figure 1 shows a two-way link with the decision/evaluation system and the communication system.

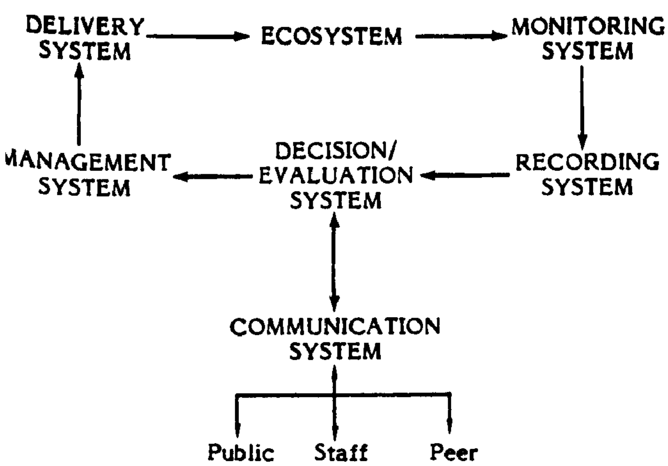

Figure 1. A management support system for an ecosystem or research site.

The implementation of effective pest management practices depends on the support and development of basic research to provide the necessary tools. Knowledge of the ecology and population dynamics of the IFA and its impact on the environment is also vital to developing effective pest management programs. In addition, methods of survey, detection, and control (including non-chemical, cultural, mechanical, physical, and biological) must be developed. Research is also needed on specific solutions to specific problems caused by the IFA; these solutions may not necessarily involve control.

1. Economics

The economic impact of IFA as a human and animal pest is difficult to assess. Before any pest management system can be effectively implemented, a cost-benefit analysis must be made. The economic losses need to be balanced against the economic benefits provided by the IFA. Will control lead to other pest outbreaks? If the IFA is eliminated from an area, repopulation usually occurs within one year. Is this due to a void left by the IFA's removal, and can this void be filled with another non-pest species of ant that would provide the beneficial effects of the IFA?

The human health problem needs to be more clearly defined. More accurate data are needed on the number of people stung, the number that develop hypersensitivity, and the economic and psychological effects of these attacks (Adams and Lofgren 1981, Lofgren and Adams 1982, Clemmer and Serfling 1975, Rhoades et al. 1977). The factors in the venom that cause the anaphylactic reaction must be identified so that measures can be developed for people whose lives are threatened.

2. Ecology and Population Dynamics

Our present knowledge of IFA ecology and population dynamics is rudimentary, at best, and filled with major gaps. Little information exists on age-specific mortality, development rates, colony growth rates under various conditions, reproduction, limits to growth, factors controlling growth, and many other subjects. There is little quantitative information on trophic relations with respect to growth and reproduction, and on the limitations food imposes on growth and reproduction. Interaction of the colony with the environment is also poorly described, and the effects of season, temperature, and rainfall are understood only generally. For this and other reasons, estimates of the potential range of the IFA are mere guesses.

There is even less information on the population dynamics of colonies. No information exists on the life span of colonies under various conditions nor on the age-specific mortality among colonies throughout the colony cycle. Such information is essential to understand the vulnerable phases of the life cycle at which pressure might be applied most effectively. Also along these lines, only very general, non-quantitative information is available on the process of colonization of a new habitat, be it on the spreading margin of the IFA range, or in long-occupied areas. What site preferences are involved in colonization? How do physical and biological factors affect success? What is the nature of inter-colony relationships as the colonies increase in size? The role of territorial behavior? And so on, for a long list of unanswered questions.

Finally, at the level of the relationships of IFA colonies to other plants and animals in the community, we have another knowledge vacuum. Because it seems so important to IFA success, the relationship of IFA to other ants greatly demands study. It is becoming apparent that other ants may become key considerations in any management attempts. Information of IFA exploitation of the community, both plant and animal, and its impact upon that community is also largely unavailable.

3. Biology

Social biology of the IFA has received some attention, but much remains arcane. While the role of the queen is generally obvious at a crude level, many questions of queen function and queen number remain unanswered. Why are there sometimes multiple queens, how do they affect colony function, queen replacement, colony growth and reproduction?

A thorough understanding of the ant's feeding behavior and social interactions is needed. Research on foraging strategies of workers, recruitment to food, natural attractants and repellents, changes in food preference, distribution of food within the nest, and the influence of foods or bait type on the distribution of control agents are needed to develop more effective, species-specific, safer baits.

Development times, conditions that trigger the production of reproductive forms, age of the colonies, the life span of the various castes, as well as colonies, and queen replacement, colony recognition, social communication (apart from the behavioral chemicals), are but a few of the biological factors that need to be investigated for effective management of this insect.

4. Physiology

The endocrine system regulates many behaviors and functions of the ant colony yet there is little knowledge concerning this important system. Research on endocrine glands is needed if we are to understand IFA reproduction and development, queen tolerance, the problem of single vs. multiple queen colonies, control of mating, caste determination, gene expression, and others.

The nutrition, digestion, and absorption of foods is important to the success of the colony. Very little is known about essential nutrients for colony growth and about IFA enzyme systems and their specificity. Studies in these areas could lead to new control methods because growth, development, reproduction, and competition are readily influenced by colony nutrition.

A study of the biochemical transformations which the IFA is capable of could be useful because compounds not metabolized by the ant can be used to design control methods based on analogs of metabolizable compounds, such as hormones or the more degradable toxicants. The biosynthetic pathways for the pheromones, venom alkaloids, and other chemicals utilized by the ants need investigation.

The flight muscles of the queen are extremely important because they are used in the mating flight and dispersal of the queens and provide food for the larvae during colony founding. Interference with colony founding might be possible if this process were better understood.

Mating and colony foundation may be vulnerable points in the IFA's life cycle, but the physiological details are virtually unknown. What triggers the mating flight? Are pheromones involved? How is wing casting initiated? How far do the sexuals fly? How does the queen select sites for colony foundation?

5. Control Tactics and Management Strategies

Chemical Control: In addition to a search for slow-acting compounds that kill, bioassays to detect compounds that interfere with other biological processes need to be developed. These could include spermaticides, reproductive inhibitors, or muscle inhibitors. Techniques for field evaluation of control tactics must be improved so that the effectiveness of compounds for control can be evaluated.

Insect growth regulators show promise, but more research is needed on their metabolic breakdown, distribution, and persistence. Also, field tests should be extended to determine the best way to utilize the insect growth regulators for IFA control, keeping in mind that these materials will not be specific to IFA. Along this line, behavioral chemicals offer great promise as they may provide specificity for baits, lead to new baits, and interfere with the social organization of the colony.

Behavioral chemicals may lead to new delivery systems that might be useful for introduction of a pathogen. Pathogens will probably require delivery systems quite different from those for toxicants.

Biological Control: Pathogens, parasites, and predators may have potential for controlling or managing the IFA; however, no effective biological control agents have been found. Part of the difficulty is the lack of research, study facilities, and financial support in the IFA's homeland where such biological control agents would most likely be found. An IFA research station needs to be developed in South America.

Genetic Control: Because the IFA has a haplo-diploid sex-determining system, development of a sterile male control tactic may be possible. Also, because the IFA mate only once, an artificial mating technique that has been developed may prove useful in a management program. Genetics is also important in other ways such as biological control and taxonomy.

Physical and Cultural Control: Research is needed on interrelationships of IFA to the conditions created by different types of land management (i.e., various types of plows and cultivators, frequency of cultivation and tilling in annual crops, and the time of year of cultivation). Trends toward no-tillage crop production additionally support these needs. However, more detailed population dynamics studies on IFA interaction with other species in these various habitats under cultural changes is an essential component to answering these needs. The potential interactions of the IFA with weeds and associated fauna are additional areas for study. In most annual crops, however, the pest status of the IFA remains undetermined.

The potential for making valuable contributions and increasing the impact of control tactics in this important area depends heavily on the quality and extent of population dynamics research. Only when the ecology of IFA at both the mound and community levels is better understood are we likely to realize applied advances in physical and cultural controls. Because these types of control tactics often have some of the greatest long-term impact on pest populations, this research merits some of the highest priority. Relating this research to ecological studies also will help clarify the true pest status of the IFA as it interacts with more traditional pests in production agriculture.

SPECIAL ORGANIZATIONAL ISSUES & AGENCY RESPONSIBILITIES

Due to the establishment of the IFA in a variety of habitats, the responsibilities for its management reside with different organizations ranging from the home owner to federal agencies. Because of this situation, the responsibilities of the organizations concerned with IFA research, education, and management must be defined, and a mechanism to provide effective, safe, and economically feasible management programs must be established. The mechanism should provide short and long-range planning to address the needs for research, education, operations, and regulatory agencies.

Research

USDA/ARS and the SAES's of the affected states conduct IFA research. Yearly meetings of an IFA working group help coordinate the research activities of the USDA/ARS and SAES's. Congress has authorized the ARS to conduct mission-oriented research on the IFA to support federal and state-controlled programs. This research includes developing chemical and biological methods to control the IFA. In addition, the research provides information and control techniques for the general public.

The SAES's are mandated by their legislatures to conduct research and to develop IFA management strategies to meet the needs of the public. This research varies from state to state, and cooperative programs are encouraged to effectively utilize human and financial resources and data exchange. Basic and applied research on IFA biology, behavior, population dynamics, systems ecology, and control strategies are being conducted. Unfortunately, little or nothing has been done to determine pest status and economic thresholds for this insect.

Education

The IFA has become a volatile emotional and political issue debated in public and private, frequently on the basis of gross ignorance or misconceptions about the insect and the problems it poses. The insect has not escaped the attention of any segment of the population within its present range, and is an issue even well outside of its range. There is an important need for an educational program, organized and promulgated by a responsible and authoritative agency, to ensure that those who need or desire accurate information about the IFA can obtain it easily. The program should be structured so as to reach specific audience groups with information appropriate to their respective needs. Among the more important of these groups are lay citizens in urban and agricultural areas; members of the news media; special interest and civic groups, such as those concerned with environmental quality or gardening; state and federal legislators; appropriate administrators at all levels of federal, state, and local government; and members of pest or agriculture-related businesses. Each group needs information relevant to the fulfillment of their role in society be it as public officials involved in making decisions relevant to IFA or as private citizens exposed to IFA.

Reliable, objective, and unsensationalized information on the nature of the problem posed by IFA is of greatest immediate need because this is the issue around which most public and private debate revolves. The medical problem should be defined on the IFA as a nuisance to the average human and as a hazard to sensitive individuals. The problem in terms of the numbers of sting victims and deaths due to stings, the relative hazard in various situations (e.g., urban, rural) and the availability of preventive medical treatment for the overly sensitive should be fully explained. Livestock, poultry, and agricultural production problems also should be explored in depth. In all cases, it will be important to differentiate between perceived problems, based on opinion or unsubstantiated anecdotal evidence, and demonstrable effects resulting in medical, economic, or ecological harm or benefit.

The public needs information to be able to accurately assess any IFA problem they may face to determine whether or not remedial action is necessary, and if necessary what action would be most beneficial (chemical or nonchemical). To broaden their understanding of the IFA, the public also should be educated on the biological role of the IFA in the environment.

These educational needs are admirably suited to the missions and capabilities of the Extension Service of the USDA and the cooperative extension services of the affected states. Information should be collected and collated at the federal level by the Extension Service and should be disseminated through the cooperative extension services for adaptation and use in their respective extension programs. In addition, it will be equally or more important for Extension to be actively involved in the educational phases and information dissemination of new technology as it is developed by research.

Role of APHIS in IFA Program

The Animal and Plant Health Inspection Service (APHIS), as mandated by Congress under three plant pest acts, is responsible within the USDA for survey, regulatory, and control activities of the IFA. Due to the anticipated cancellation of mirex and chlordane, an ARS/APHIS Working Group was formed in 1977 to study future control technology, including chemicals, that could be used by APHIS and its cooperators in future IFA programs. The Working Group consists of three scientists from each of the two services who carefully review research needs and the research and methods development efforts that jointly affect the ARS and APHIS.

Soon after creation of the Working Group, it became apparent that there was a need to involve other services from within the USDA, the states, the EPA, and the chemical industry to expedite urgently needed "tools" to regulate and control the pest. Consequently, the Working Group has guided progress to date with invited input from the states, EPA, and chemical industry. This procedure could be developed into a permanent policy and decision-making mechanism to plan all future programs involving the IFA.

It is anticipated that the APHIS will continue to carry out its mandated charter of IFA survey and regulatory responsibilities in conjunction with its cooperators. Involvement of APHIS in future IFA control programs will depend on its congressional mandate. It should be noted that Panel I of this Symposium concluded that a rationale does not exist for large-scale IFA eradication or control programs. Such federally-supported programs have not been successful in eradicating the pest nor in keeping it from being widespread in the southeastern United States. This suggests that the role of APHIS in IFA programs should be the same as for any other established pest species.

Regulatory

As mandated by Congress under the Federal Insecticide, Fungicide and Rodenticide Act (FIFRA), the EPA is responsible for pesticide registration. To adequately evaluate the environmental impact of potential IFA controls (chemical or biological), the EPA needs specific data demonstrating the safety and utility of the controls. These data generally include product chemistry, toxicology, environmental chemistry, ecological effects, and efficacy information. The extent and volume of specific tests needed for IFA control primarily depend on (1) target sites, i.e., agricultural vs. non-agricultural, rural vs. urban; (2) use patterns including rates and methods of application, i.e., aerial, ground broadcast, mound treatment, quarantine; (3) user groups, i.e., agricultural, commercial, PCO, homeowners; (4) size of treatment area; and (5) pesticide classification of the compound (biological, biorational, conventional pesticide).

Early access to the above information would enable EPA to (1) evaluate the existing data base on old and new IFA control agents and (2) identify data gaps, research needs and/or environmental problems early in the planning activity. This would then enable EPA to provide an appropriate and timely decision on an IFA pesticide—approving or denying registration, requiring further studies, or waiving additional data. In addition, EPA's regulatory responsibilities can better serve future IFA control programs if it can participate in the preliminary deliberations concerning future management strategies.

RECOMMENDATIONS

1. Determining the pest status and developing economic thresholds for the IFA in various ecosystems should receive the highest priority for additional research. Furthermore, pest management strategies should be developed for the IFA. However, because most of the tactics needed for such an IPM program have not yet been developed, additional funding should go to basic and applied research. The information from this research would enhance the development of practical and effective pest management strategies for the IFA by providing a better understanding of the biology and ecology of the ant in each of its habitats.
2. The research should include investigations for effective and economical alternative chemicals as well as non-chemical methods. The latter efforts should emphasize biological and non-chemical alternative control measures suitable for homeowner use.
3. To provide responsible agencies with a

clearer definition of the existence and scope of the problem, an unbiased third party should conduct a thorough scientific survey on the economic and human health importance of the IFA. To assist this third party, a small resource panel could be formed, consisting of an economist, one or two representatives from SAES, and a representative from each of EPA, APHIS, ARS, a state department of agriculture, and a public health agency.

4. An educational program should be organized and promulgated by a responsible and authoritative agency to ensure easy access to accurate and useful information on the IFA. The program should reach specific audience groups with information appropriate to their respective needs. The agencies to fulfill these educational needs are the Extension Service of USDA and the cooperative extension services of the affected states.

5. Chlordane should be re-registered <u>for quarantine treatment use only</u>, until a suitable and satisfactory alternative is found.

6. A comprehensive research planning and action program should be developed and implemented through existing or new mechanisms of the Southern Regional Association of State Agricultural Experiment Stations. Existing mechanisms provide for strong interaction between all interested state and federal agencies.

7. An InterAgency Task Force should be established to mobilize available resources to develop a comprehensive 5-year program to include research, education, and action activities to develop management strategies for the IFA. Key agencies should include APHIS, ARS, CSRS, Extension and ERS of USDA; the EPA; the state agricultural experiment stations, cooperative extension services, and state departments of agriculture in affected states; and various state universities. Other agencies with an interest in the IFA include DOD and NIH. The NSF should be encouraged to support research on other ant species to provide basic knowledge that could contribute to the development of IFA management programs.

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Appendices

APPENDIX A

CHEMISTRY AND PROPERTIES OF FIRE ANT VENOMS

Murray S. Blum

PANEL IV

The venom of the fire ant, *Solenopsis invicta*, in common with those other species in this genus, is distinguished by the presence of dialkylpiperidine alkaloids that have not been detected as natural products of species in any other taxa. These idiosyncratic alkaloids constitute about 95% of the poison gland secretion, being accompanied by a denser aqueous phase that contains traces of proteinaceous constituents. These protein-poor, alkaloid-rich venoms contrast with those of most stinging ants which are characterized by high concentrations of biologically active proteins and the absence of detectable alkaloidal constituents.

The venom of workers of *Solenopsis invicta* is dominated by six 2-methyl-6-alkylpiperidines that are present primarily as *trans* isomers; the *cis* isomers are relatively minor constituents. The major alkaloid produced is *trans*-2-methyl-6-(*cis*-6-pentadecenyl) piperidine, *Trans*-2-methyl-6-(*cis*-4-tridecenyl)-piperidine also constitutes a quantitatively important constituent, whereas 2-methyl-6-(*cis*-8-heptadecenyl) piperidine is a minor venomous product. The major saturated alkaloids are *trans*-2-methyl-6-*n*-tridecylpiperdine and *trans*-2-m ethyl-6-*n*-pentadecylpiperidine. *Trans*-2-methyl-6-*n*-undecylpiperidine is a quantitatively unimportant product.

The venoms of the four other fire ant species in North America are qualitatively less complex than the venom of *Solenopsis invicta*. The venom of workers of *S. richteri*, another introduced species lacks the dialkylpiperidines with 6-alkyl side chains greater than C_{13}. The venoms of workers of the three native species, *S. xyloni*, *S. geminata*, and *S. aurea*, are qualitatively depauperate compared to *S. invicta* and *S. richteri*. In general the venoms of these native fire ants contain only the *cis* and *trans* isomer of 2-methyl-6-*n*-undecylpiperidine, with the former isomer predominating. The venom of *S. xyloni* is unique in containing 2-methyl-6-undecyl-$W^{1,2}$-piperidine as a minor constituent, a compound that may constitute an intermediate in the biosyntheses of the *cis* and *trans* isomers of 2-methyl-6-*n*-undecylpiperidine.

In contrast to the qualitative diversity that characterizes the venoms of workers of *S. invicta* and *S. richteri*, those of their queens are depauperate. The venoms of the queens are dominated by the *cis* and *trans* isomers of 2-methyl-6-*n*-undecylpiperidine, the former isomer always predominating.

None of the dialkylpiperidines with 6-alkyl side chains greater than C_{11}, which dominate the venoms of the workers of *S. invicta* and *S. richteri*, are present in the venoms of the queens. The venom of the queen of *S. richteri* is also distinguished by the presence of trace amounts of 2-methyl-6-*n*-nonylpiperidine. In contrast, the venoms of queens of *S. xyloni* and *S. geminata* are similar to the venoms of their workers in primarily containing the *cis* and *trans* isomers of 2-methyl-6-*n*-undecylpiperidine.

Considering the *cis* isomers as being thermodynamically favored from an energetic standpoint, a hypothetical phenocline in biochemical evolution for the genus *Solenopsis* was constructed. The venoms of the queens of *S. xyloni* and *S. geminata* reflect the more primitive state, being qualitatively simple and dominated by the *cis* isomer of 2-methyl-6-*n*-undecylpiperidine. The venoms of the workers essentially mirror those of their queens. Evolution of a form in which the *trans* isomers predominates (a South American species) in the worker venom would be followed by elaboration of new *trans* alkaloids in worker venoms with a 6-alkyl side chain greater than C_{11} (*S. richteri*) eventuating in a form with side chains containing C_{15} and C_{17} moieties (*S. invicta*). Since the venoms of workers of *S. invicta and S. richteri* are considerably more necrotoxic than the simple venoms of *S. xyloni* and *S. geminata*, it is suggested that the evolution of new *trans* alkaloids was highly adaptive for the former pair of species.

Three to four proteins are present in the minor aqueous phase in the venom of *S. invicta*. One of these macromolecular constituents is hyaluronidase; the other is phospholipase. Since the latter enzyme is considered to be the primary allergen in hymenopteran venoms, these minor proteinaceous constituents probably are responsible for the allergic reactions experienced by some human beings after being stung by workers of *S. invicta*.

The dialkylpiperidines present in *Solenopsis* venoms possess a wide range of biological activities that had been previously identified with these poison gland secretions. The venom of *S. invicta* exhibits well-developed fungicidal, bactericidal, insecticidal, herbicidal, and hemolytic activities; all of these properties can be duplicated with the neat alkaloids. The fungicidal activities of some of the dialkylpiperidines are equal to or are greater than those of commercially available fungicides. The pronounced necrotoxicity of the venom, that results in sterile pustules at the sting sites on human beings, is directly attributable to the alkaloids.

A variety of other biochemical lesions are produced by the dialkylpiperidines. These alkaloids degranulate most cells, which frees a histamine and produces algogenic and allergic reactions in humans. Additionally, these compounds inhibit ATPase and oxidative phosphorylation, and deleteriously affect sites at the vertebrate neuromuscular junction. These pharmacological activities illustrate the wide range of biochemical lesions that these unique alkaloids are reported to produce in *in vitro* investigations.

APPENDIX B

THE MEDICAL ASPECTS OF THE IMPORTED FIRE ANT

William H. Schmid, M.D.

PANEL IV

Hypersensitivity reactions to stings of winged Hymenoptera have been described since antiquity. The imported fire ants, *Solenopsis richteri* and *Solenopsis invicta*, which have been present in the southeastern United States for 40 to 50 years, cause significant medical morbidity by their stings. In an infested area, IFA stings occur more frequently than do bee, wasp, hornet and yellow jacket stings. The human reaction to the stings of these two IFA species is similar.

The IFA sting produces an uncomfortable burning sensation and usually results in the formation of a sterile pustule, 3-5 mm in diameter at the point of the sting. The pustule usually disappears after a few days. Multiple stings from IFA occur because individual ants can administer several stings. The average victim has several stings and 10 to 20 stings are common. The primary site is characterized by redness followed by a wheal and a characteristic pustule within six to twenty-four hours. The pustule is diagnostic of an IFA sting.

The overwhelming majority of IFA stings are uncomplicated. A pigmented area often develops at the sting site which persists as a blemish for weeks to months. Secondary infections can occur when the pustule is broken. Impetigo is the most common secondary infection. Severe infections have occurred requiring skin grafting, amputation of an extremity or digit, or incision and drainage of a wound.

Some people experience a generalized allergic reaction to an IFA sting. These reactions occur within minutes of a sting and vary in severity. The reactions can include generalized hives, facial, genital or extremity swelling, nausea, vomiting and shock. Death also can occur. Feet and ankles usually are stung. The ant anchors to the skin with its mandibles and then stings once or several times with its abdominal stingers.

The following histories demonstrate the variety of sting situations.

Case I

A 32-year-old Canadian male was stung by 10 ants while changing a tire on the edge of the interstate highway in St. Petersburg, Florida. He became weak and fainted and was taken to a hospital emergency room where he was found to be in shock and was hospitalized. He recalled hymenoptera stings in Canada without difficulty. This was his first visit to a fire ant infested area and his first known fire ant sting.

Comment: Over 20% of patients with anaphylaxis following an IFA sting have a severe reaction on the first sting.

Case II

A 25-year-old, male, golf-course worker experienced repeated severe reactions to IFA stings that required emergency room treatment. He was placed on a fire ant desensitization program and subsequently could tolerate IFA stings without difficulty. However, he was stung by a wasp and died in shock 30 minutes later. There was a childhood history of bee and wasp stings without difficulty.

Comment: The incidence of associated bee and wasp sting hypersensitivity is higher among IFA-sensitive patients than in the normal population. Desensitization programs are effective in reducing the severity of reactions in IFA-sensitive patients. These programs will lessen the sensitivity to IFA stings, but not to bee or wasp stings if the patient is also sensitive to these insects.

Case III

An 81-year-old male was found comatose on a fire ant mound in a field near his home and taken to an emergency room. He had multiple bites of the trunk, face, extremities, and genitalia. Live ants were found in his mouth and nose. The man was intubated and placed on assisted ventilation. Fire ants were recovered from the trachael intubation tube and from uretheral catheter drainage. He was admitted to an intensive care ward to the care of a physician who felt that the patient had a stroke. The patient was completely well the day following admission and the diagnosis was revised to anaphylaxis to fire ant stings.

Comment: Some elderly patients are hospitalized because of shortness of breath, and shock which is attributed initially to heart disease. The correct diagnosis usually is made the day following admission when the characteristic pustules are noted.

Case IV

A 25-year-old female was stung by ants in Hattiesburg, Mississippi. She developed immediate wheezing and confusion, followed by shock. She was taken to an emergency room where she was intubated and placed on assisted ventilation in an intensive care ward. She recovered and was discharged. She moved to St. Petersburg, Florida, where she again was hospitalized for a severe reaction to a fire ant sting.

Comment: There appear to be no geographical differences in the severity of fire ant hypersensitivity reactions.

Case V

This 4-year-old child has experienced

four episodes of hives, facial swelling, and wheezing after fire ant stings. These reactions have required emergency room treatment. Subsequently, her parents do not allow her to play outdoors for fear of future stings.

Comment: Fire ant sensitivity is a special problem in young children who are unable to avoid fire ants in outdoor play.

Case VI

This 63-year-old male tourist from Minnesota with known angina pectoris developed severe chest pain, hives, and shortness of breath after a fire ant sting. He was hospitalized in a coronary care unit where he recovered uneventfully.

Comment: A hypersensitive reaction to a fire ant sting in a patient with underlying cardio-vascular disease can be a fatal event.

SUMMARY

In infested states, a hypersensitive reaction to a fire ant sting should be suspected when a patient is seen with unexplained acute hives or shock. Complications from IFA stings cause considerable medical expense, human morbidity, and occasional mortality. Until an acceptable means of control is developed, physicians practicing in the infected areas can expect to treat many complications from the sting of the insect.

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APPENDIX C

A BRIEF HISTORY OF CHEMICAL CONTROL OF THE IMPORTED FIRE ANT

R.L. Metcalf

PANEL IV

INTRODUCTION

The development of chlordane in 1944 (Kearns et al. 1946) provided the first effective synthetic organic insecticide against ants (Formicidae). Chlordane (1,2,4,5,6,7,8,8-octachloro-2,3,3a,4,7,7a-hexahydro-4,7-methanoindene) became the standard remedy for controlling ants about premises--a position it occupies today. Chlordane is synthesized from cyclopentadiene which is the reactive raw material that became the base for a variety of other cyclodiene insecticides including heptachlor (1,4,5,6,7,8,8-heptachloro-3a,4,7,7a-tetrahydro-4,7,-methanoindene) and dieldrin (1,2,3,4,10,10-hexachloro-6,7-epoxy-1,4,4a,5,6,7,8,8a-octahydro—*endo*-1,4-*exo*-5,8-dimethanonaphthalene). These compounds were several times more toxic to ants than chlordane. Dieldrin, as an epoxide, was environmentally the most stable and persistent. Heptachlor, because of its C_2=C_3, could be oxidized environmentally and biochemically to form heptachlor-2,3-epoxide—an even more toxic compound whose environmental persistence rivaled that of dieldrin.

The availability of these effective and highly persistent formicides coincided with the expansion of the imported fire ant's (IFA) area of infestation (*Solenopsis invicta*) (Buren et al. 1974). Heptachlor and dieldrin were seen as the most promising weapons for area-wide IFA control programs.

HEPTACHLOR AND DIELDRIN

With ample funding from Congress, the USDA undertook a massive IFA eradication program covering millions of acres in Florida, Georgia, Alabama, Louisiansa, and Texas. The plan was to treat all infested lands with 20 lb. of 10% granular heptachlor or dieldrin per acre. This dosage [2 lb AI (active ingredient)] was considered sufficient to eradicate the IFA and to prevent reinfestation of the treated area for a minimum of three years. This treatment was conducted for two years with heptachlor being used more extensively than dieldrin.

Heptachlor and dieldrin are environmentally persistent and toxic to terrestrial and aquatic wildlife (Pimentel 1971), yet little consideration was given to the environmental hazards of these chemicals to non-target organisms, and the eradication program had virtually no research component to examine such hazards. Damage to wildlife in the treated areas was immense. As a result, at the start of the third year of the eradication program, treatment rates were reduced to 1.25 lb. technical heptachlor per acre. Experiments were conducted with two 0.25 lb per acre treatments at a three month interval.

Wildlife studies in Hardin County, Texas, showed that opposums, armadillos, and an abundant racoon population virtually disappeared and were still depressed during the second season after treatment with heptachlor. Racoons that repopulated the area were contaminated with heptachlor epoxide residues in the kidney averaging 19.9 ppm (parts per million) after two weeks, 3.8 ppm after six months, 7.8 ppm after nine months, and 4.5 ppm after one year (DeWitt and George 1960). Birds were particularly devastated. Evaluations showed that in Texas and Louisiana the bird population declined over 85% following treatment; nesting successes were reduced by 89% or more and remained depressed the following year. Ground birds were severely affected (Tables 1 and 2).

Dead animals found within three weeks after treatment in areas of Texas, Louisiana, Alabama, Georgia, and Florida were analyzed for total body residues of dieldrin or heptachlor epoxide. More than 98% of the dead animals contained detectable residues. These were highest in a wide variety of birds whose averagebody residues were (1) dieldrin: 17.9 ± 4.3 ppm (18 species) and (2) heptachlor epoxide: 15.3 ± 8.6 ppm (30 species). Residues were found in a variety of mammals, fish, reptiles, and amphibia

Table 1. Reduction of ground birds in Montgomery County, Alabama, 1959, following heptachlor or dieldrin treatments for imported fire ant control.

Strata	Reduction
low or ground (7 species)	100%
low to intermediate (17 species)	50-99%
intermediate to high (19 species)	no effect

Table 2. Surveys of birds seen in Wilcox County, Alabama, following treatment for imported fire ant control.

Treatment	Live Birds Seen Per Mile	
	Robins	Meadowlarks
heptachlor	0.0	0.2
heptachlor	6.0	0.0
dieldrin	0.0	0.0
untreated	22.8	25.7

(DeWitt et al. 1960). Where granular applications were made to salt marshes and other aquatic areas, the fish populations were eliminated or seriously damaged.

The extensive damage to wildlife from the IFA eradication program alarmed conservationists. Rachel Carson (1962) described the program as ill conceived, badly executed, and a thoroughly detrimental experiment in insect control that resulted in both the destruction of animal life and in loss of public confidence in the USDA. She found it incomprehensible that any public funds were still devoted to it. The misuse of heptachlor and dieldrin in the early stages of the IFA eradication program was a critical part of the accumulated environmental outrage that created Silent Spring and resulted in public disenchantment concerning the widescale use of pesticides.

About 20 million acres were treated during the five years of the early eradication program. From 1957 to 1962 however, the area infested by IFA had increased from 90 million acres to about 126 million acres

MIREX

In the search for a more ecological way to control IFA, many synthetic organic chemicals were evaluated. Hays and Arant (1960) at Auburn University showed that peanut butter baits containing 0.125% chlordecone (Kepone) (1,2,3,5,6,7,8,9,10,10-dodecachlorooctahydro-1,3,4-metheno-2*H*-cyclobuta-[*cd*]-pentalen-2-one) (another cyclodiene product of hexachlorocyclopentadiene) gave excellent IFA control. The USDA Methods Development Laboratory at Gulfport, Mississippi found that a very closely related cyclodiene, mirex (1,2,3,4,5,5,6,7,8,-9,10,10-dodecachloro-octahydro-1,3,4-metheno-2*H*-cyclobuta-[c,d]-pentalene) was as effective as chlordecone and was less toxic to non-target species (Lofgren et al. 1962). An IFA bait formulation was developed consisting of once-refined soybean oil as food, corncob grits as carrier, and mirex as toxicant. The bait was effective at rates as low as 4.2 grams of mirex per hectare (1.7 grams per acre). During development it was found that increasing the mirex content from 0.075% to 0.3% substantially reduced the bulk rate of application. This bait, properly applied, averaged 98% control of IFA from ground applications and 96% control on large acreages treated by aircraft (Lofgren et al. 1975). In 1962, 0.3% mirex bait became the standard IFA control agent (Alley 1973).

Mirex had a delayed stomach poison action that appeared ideal for IFA control. Its properties included: (1) delayed killing action over a 10 to 100 fold dose range, (2) easy transfer between ants through regurgitation, resulting in death of the recipient, often the queen, and (3) attractiveness to the IFA (Waters et al. 1977). Secretary of Agriculture Orville Freeman hailed mirex as the perfect pesticide. "It has no harmful effect on people, domestic animals, fish, wildlife, or even bees, and it leaves no residue in milk, meat, or crops" (Whitten 1966, Science 1971).

Armed with mirex, the USDA planned a massive eradication program that included all 126 million acreas infested by the IFA. The program was to be conducted over a 12 year period at a cost of $200 million that would be financed as a matching fund operation between the USDA and the participating states. Subsequently, a National Academy of Science Committee (Mills 1967) reported that eradication of the IFA was biologically and technologically impossible and was inadvisable if it were possible. USDA eradication trials conducted with the mirex bait (Banks 1972), however, were interpreted as demonstrating the feasibility of eradication with three or four sequential applications of the mirex bait.

In retrospect, mirex is far from the "perfect insecticide." Mirex contains no carbon-hydrogen bonds and is one of the most environmentally stable xenobiotics known. Mirex was first synthesized by McBee et al. (1956) and was patented as an insecticide (Belgium pat. 624, 256, April 30, 1963, French pat. 1,338,074, September 30, 1963) and, because of a melting point of 349^{o}C, as a flame-retardant (U.S. Pat. 3,-494,973, February 10, 1970). Mirex is soluble in water to about 20 ppb and has an octanol/H_2O partititon coefficient of about 10,000. In laboratory model ecosystem studies, (Metcalf et al. 1973), ^{14}C mirex shown to bioaccumulate through food chains and to persist, virtually undegraded, in alga, mosquito larva, snail, and fish (98-99% parent compound). Rats eliminated 18% of ^{14}C mirex as unmetabolized mirex; the remainder was stored in body tissues (Gibson et al. 1972).

The use of mirex was followed by evidence of its persistence and biomagnification. In an area of Louisiana that had received six applications of mirex bait at 1.25 lb. per acre over a four year period the following residues were found: 0.01 to 0.75 ppm in snails, crayfish and fish; 1.2 to 1.91 ppm in birds; 24.82 ppm in the fat of soft-shell turtles; and 73.94 ppm in the adipose tissue of vertebrates at the top of the food chain (Hyde et al. 1973). In an estuarine environment, mirex in the water at 0.5 ppb was found to bioaccumulate to 20.4 ppm in minnows (40,800X), to 5 ppm in shrimp (10,000X), and to 1.5 ppm (2,300X) in blue crabs (Tagatz et al. 1975). A survey of birds from South Carolina, Georgia, and Florida showed an average value of 4.32 ppm (liquid weight) of mirex in eight birds (Dreitzer 1974), while starlings contained levels of 0.1

to 1.66 ppm (Oberhen 1972). Adipose tissues of persons living in treated states were found containing mirex in amounts ranging from 0.16 to 5.94 ppm (Kutz et al. 1974). More recently mirex residues were found in 23% of adipose tissues from 624 inhabitants of eight southern states (EPA 1980, Severn 1982-Appendix F).

As a result of these disclosures, the Environmental Defense Fund (EDF) brought suit in August 1970 to terminate the USDA IFA program. The EPA issued a cancellation order for the use of mirex, effective March 18, 1971. Allied Chemical Company, the sole manufacturer of mirex, protested the cancellation. Following hearings, the EPA issued new guidelines for a modified control program. However, entomologists in many of the cooperating states began opposing the program, and the eradication program began to die when several states withdrew their matching support (Shapley 1971).

Meanwhile, additional concerns had developed about the continued use of mirex. Approximately 3,361,000 lb. of mirex were manufactured at Niagra Falls, N.Y. between 1959 and 1975. Mirex-containing effluents from manufacturing and waste disposal contaminated the southern waters of Lake Ontario with concentrations from 1 to 10 ppb. A variety of fish from the lake contained whole-body residues of mirex, with mean levels of: white perch 0.10, smelt and small mouth bass 0.13, coho salmon 0.17, chinook salmon 0.21, and lake trout 0.22 ppm. The maximum level recorded was 1.20 ppm. Residues of mirex were found in the eggs of herring gull, cormorant, gyrfalcon, prairie falcon, peregrin falcon, and pigeon hawk. In the pigeon hawk, these residues had a mean value of 0.25 ppm and ranged from 0.01 to 3.16 ppm (Kaiser 1978).

Mirex undergoes slow environmental degradation by both photochemical and microbiological processes and forms two monohydroderivatives ($C_{10}HCl_{11}$), two dihydro-derivatives ($C_{10}H_2Cl_{10}$), and chlordecone (Kepone®), the 2-C=0 derivative ($C_{10}Cl_{10}0$). Alley et al. (1974a,b) explored the photochemistry of mirex and chlordecone. Samples of mirex fire ant bait exposed to the elements for five years contained 75.9 to 81% of mirex, 7.4 to 8.3% mono-hydro mirex or photomirex, and 1.3 to 5.7% chlordecone (Carlson et al. 1976). Concern over the formation of chlordecone from mirex was heightened by the Hopewell, Virginia, experience where the James River and much of Chesapeake Bay were contaminated with an estimated 100,000 lb. of chlordecone (Kepone) effluent. Factory workers suffered reproductive difficulties due to the estrogenic properties of this substance and developed severe symptoms of delayed neurotoxicity (Sterrett and Boss 1977).

Mirex and chlordecone were found to be

animal carcinogens. Lifetime feeding of mice with mirex at 26 ppm in the diet produced liver hepatomas in 45% as compared to 4% of the control mice (Innes et al. 1969). Lifetime feeding of mice at 20 to 40 ppm with chlordecone produced hepatocellular carcinomas in 81 to 88% of males and 47 to 52% of females compared to 16% in male controls and 0% in female controls (National Cancer Institute 1976).

Due to the continued concern over public health and environmental quality aspects of the large scale deployment of mirex bait, EPA banned the use of mirex. As a result, Allied Chemical Company sold its plant in Aberdeen, Mississippi, to the state for $1. Mississippi then established an Authority for the Control of the Fire Ant within the Department of Agriculture and Commerce. In October 1976, EPA and Mississippi agreed to terminate aerial application of mirex baits by December 31, 1977, and to permit ground applications only through June 30, 1978. At that time the pesticide registration of mirex was cancelled.

Studies of the photodegradation of mirex showed that environmental dechlorination to photomirex and to further dechlorination products could be accelerated by adding aliphatic amines and ferrous chloride (Alley et al. 1974c). An IFA bait formulation ferriamicide, was developed to contain 0.05% mirex, 1.7% amine (Keramine T 1902D), 0.2 ferrous chloride hexahydrate, and 8% soybean oil. This formulation is to be applied at 1.5 lb per acre equivalent to 0.227 grams mirex per acre. The ferriamicide formulation reduces the environmental half-life for mirex from 12 years to about 0.15 years (Alley 1982-Appendix F). Concern over the production of the highly toxic photomirex as a principal degradation product has delayed registration of ferriamicide by EPA.

In order to avoid the persistent and non-degradable residues of the organochlorine insecticides, efforts were made to find more biodegradable organic stomach poisons. USDA scientists screened more than 5000 candidate pesticides and the most promising substitute for mirex found during the 1970's was tetrahydro-5,5-dimethyl-2-(1H)-pyrimidone-[3-(4-trifluoromethyl)-phenyl]-1[2-(4-trifluoromethylphenyl)-ethenyl]-2-propenylidene-hydrazone (trade name Amdro® Williams et al. 1980. Amdro is a slow acting stomach poison with very low water solubility, 5-7 ppb, and a low octanol/H_2O partition. It is of low acute toxicity and appears to be essentially non-bioaccumulative and environmentally degradable. Amdro is effective against IFA at 4 to 6 grams per acre when applied in a 1% soybean oil-corn grits bait. Amdro was registered conditionally for IFA control by EPA in 1980 and is available to the general public.

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APPENDIX D

IMPACT OF THE IMPORTED FIRE ANT CONTROL PROGRAMS ON WILDLIFE AND QUALITY OF THE ENVIRONMENT

Maureen K. Hinkle

PANEL IV

EARLY SPRAY PROGRAMS

In 1957, the USDA created a furor among scientists and conservationists when it unvieled its plans for eradicating the imported fire ant (IFA). Objections to the program centered on the use of the chlorinated hydrocarbon compounds heptachlor and dieldrin. Ezra Taft Benson, then Secretary of Agriculture, was asked to delay the program until some research could be conducted (1) to determine appropriate dosages and (2) to determine the effects of the compounds on non-target organisms. Despite these objections, in 1958 the USDA initiated the eradication program (see Table 1) with a $3 million appropriation from Congress.

Ground applications of heptachlor and dieldrin killed the IFA though not as well as had been forecast; however, they also adversely impacted the surrounding wildlife. The 1971 President's Study on the Ecological Effects of Pesticides on Nontarget Species described the effects of heptachlor:

> In 1957 the U.S. Department of Agriculture in a cooperative program with the States treated approximately 27 million acres in the Southeast with heptachlor at a rate of 2 lb/A for control of the imported fire ant (Smith and Glasgow, 1963). Investigations of the effects of heptachlor on wildlife were initiated after the second year of treatment in south-central Louisiana. On 4 farms the following animals died within 3 weeks after treatment: 53 mammals, including 12 species; 222 birds, including 28 species; 22 reptiles, including at least 8 species; many species of frogs; many kinds of crayfish; and many fish, including 8 species. Ninety-five percent of the dead animals were analyzed, and all contained some heptachlor.
>
> Quail populations in Georgia declined significantly soon after the land was treated with heptachlor at a rate of 2 lb/A, and the populations had not yet recovered after a period of 3 years of no further treatment (Rosene, 1965). A decline of cocks and coveys of quail also followed the 1/2-lb heptachlor applications (significant for cocks, approaching statistical significance for coveys). A small 4-acre plot within the treated area was searched for dead and dying animals and observations were made on living animals. Forty-seven days after treatment, no live animals were seen or heard on the plot, and a total of 38 dead animals had been found.
>
> A 2-year study carried out to determine the effects heptachlor treatments were having on bird popula-

tions in Mississippi disclosed that all treatment rates of heptachlor at 0.25, 0.50, and 2.00 lb/A "decimated arthropod populations, caused bird mortality, and altered bird behavior patterns." None of the dosages, however, eradicated the imported fire ants as planned.

In Silent Spring (1962), Rachael Carson described treated areas where all wildlife had been destroyed. Carson also reported deaths of poultry, livestock and domestic pets due to heptachlor, and she cited Otis L. Pointevint a veterinarian from Bainbridge, Georgia, who had treated animals within a period of two weeks to several months after the treatment. The animals had lived in areas that were treated for IFA and had access to contaminated food or water. Every animal suffered from a sometimes fatal disease of the nervous system. Five months after the application, one two-month-old calf was found with 79 ppm of heptachlor in its adipose tissues.

NEW CHEMICALS

In 1960, the FDA cancelled tolerances for heptachlor residues in pasture grasses and began exploring other chemicals. The first chemical used was chlordecone (kepone) in peanut butter (Texas A&M 1981). Chlordecone, however, was highly toxic to mammals. Research soon turned up mirex, an analog of chlordecone, which was effective against the IFA but less toxic than chlordecone. Mirex appeared to be the ideal chemical control for the IFA. Foraging workers carried the toxicant back to nesting queens, thus insuring the death of the colony. Mirex bait was comprised of 0.3% mirex as toxicant, 14.7% soybean oil as solvent and food, and 85.0% corncob grits as carrier. In 1962 this bait, known as mirex 4X, was applied over a large acreage in Georgia, Louisiana, Alabama, and Texas, at the dosage rate of 10 pounds of product per acre. Mirex was soon found to be effective at lower dosages. In 1963, the dosage dropped to 2-1/2 pounds of product per acre. In 1965, the dosage went to 1-1/4 pounds of product per acre. Belief in mirex's ability to eradicate the IFA was high. Some felt that three properly timed applications of mirex (1-1/4 pounds of product per acre or 5.1 grams of mirex per acre) over a 1-year to 18-month interval "to the entire infested area would almost eliminate the imported fire ant from the United States" (USDA 1971). This hypothesis encouraged those who favored eradication, and in 1967 the Senate Appropriations Committee directed USDA to determine the feasibility of eradicating the IFA with mirex (see Table 2). Accordingly, three large-scale eradication trials were begun.

ENVIRONMENTAL CONCERNS

With the passage of the National Environmental Policy Act (NEPA) by Congress in 1969, environmental issues found greater emphasis. The NEPA required environmental issues to be considered early in the decision-making process rather than after the fact. In 1970, the Environmental Protection Agency (EPA) was created, and pesticide registration moved from USDA to EPA. At the same time, Interior Secretary Hickel removed federal land from the mirex/IFA program.

In addition, the newly formed Environmental Defense Fund (EDF), the first environmental group formed to bring court suits on environmental problems and the organization that participated in several pesticide cancellation proceedings throughout the '70's decade, sued USDA to restrain the IFA eradication program. The December 3, 1970, settlement called for an environmental impact statement (EIS), completed January 22, 1971. In the EIS, USDA stated that eradication might be technically feasible, but logistic and financial limitations together with "possible adverse environmental effects resulting from such large-scale use of Mirex bait" made eradication "no longer an objective of the Federal-State Cooperative Control program." The three large-scale eradication trials had failed to eradicate the IFA.

USDA consequently altered the IFA control program:

> Mirex bait will be applied aerially to those areas where the ant is causing trouble, where the property owners have expressed concern, and where the State and local governmental agencies have requested Federal cooperation in a control program. Under the plan, forested areas which are not prime fire ant habitat and sensitive areas such as estuarine areas, and State and Federal game refuges will not be treated. Application pilots will be briefed with respect to all sensitive areas, including water, and instructed to avoid application to those areas. Compliance will be closely monitored by ground personnel and aerial supervision (EIS 1971) (emphasis added).

In response to questions posed by the Appropriations Committee, USDA offered the following definitions:

1. How do we define prime wildlife habitat?

   With respect to the imported fire ant control program, prime wildlife habitat is described as Federal and State game refuges, estuary and marsh areas, wooded areas bordering streams, rivers, and other bodies of water. Heavily wooded areas are not treated because they do not support imported fire ant populations (emphasis added).

2. What is the largest continuous block that would be treated under this one treatment concept?

   In open general farming areas without streams or heavily wooded areas, 50,000 or more contiguous acres may be treated. As a general guideline, if 75 percent or more of the area is open, an electronic guidance system is employed. Cutouts such as rivers, heavily forested areas, and game refuges are marked on the pilot's map, and the recording tape in the aircraft marks these areas that are cut out. When less than 75 percent of the total area is to be treated, small aircraft are used due to the many cutoffs required.

3. What do we plan to do along the peripheral areas?

   Treatments are planned in peripheral areas when there is threat of spread to uninfested States or to a new area of an infested State. These treatments are to be made in support of the Federal quarantine (EIS 1971).

PROBLEMS WITH MIREX

On March 18, 1971, within two months of USDA's environmental impact statement, EPA announced its intention to cancel mirex due to the adverse effects on wildlife and humans. Allied Chemical Company, the registrant of ten of the eleven pesticide products containing mirex, referred the issue to the National Academy of Sciences. From this came the National Research Council's (NRC) report citing adverse effects from mirex on aquatic life, particularly young shrimp and blue crabs. EPA accepted the NCR's recommendation and prohibited the use of mirex in coastal areas. (This prohibition was modified June 30, 1972, to permit applications to streams and farm ponds not used primarily for human consumption.) Combined with Interior's ban on federal lands, the restrictions posed difficulties since all affected states bordered the Atlantic, the Gulf, or major rivers and aquatic areas.

A Notice of Intent to hold a hearing on whether or not to cancel registrations of mirex was published April 4, 1972. Hearings began July 11, 1973, and continued until March 28, 1975, when settlement negotiations began. On July 14, 1975, Allied withdrew from negotiations and announced it would stop producing mirex until an agreement could be reached. Hearings resumed sporadically until February 12, 1976, when Allied stated it would no longer formulate mirex bait.

On February 26, 1976, hearings were temporarily suspended. On May 10, 1976, Allied transferred registrations to Mississippi. The hearings were dormant while Mississippi reviewed the record (13,000 pages of transcript, over 200 exhibits, testimony of over 100 witnesses).

After reviewing the record, Mississippi submitted a plan to phase out mirex registrations and suspend the hearing. On October 20, 1976, EPA accepted the plan to allow aerial application of mirex through December 31, 1977, and ground broadcast and mound application through June 30, 1978.

The impact of the IFA control programs on wildlife and the quality of the environment is summaried from EPA's decision of

December 29, 1976:

Impurities and Degradation Products. Very recent screening analyses of formulated Mirex bait at the Mississippi Authority's formulating plant in Aberdeen, Mississippi, have shown that Kepone is present in Mirex bait at levels up to 0.25 ppm and in technical Mirex at levels up to 2.58 ppm.

Recent research conducted by the United States Department of Agriculture and others has shown that as much as 10% of Mirex applied in the environment either begins as Kepone or is degraded into Kepone over periods of fire and twelve years. . . . Laboratory studies have shown that Mirex can degrade photolyticly into Kepone. . . .

Persistence. Because of its unique chemical structure, Mirex is more resistent to chemical attack than other chlorinated hydrocarbons such as DDT, Aldrin/Dieldrin, and Heptachlor. (Alley Testimony at 4). Mirex therefore will likely remain on non-living (and living) matter for longer periods of time than would such chlorinated hydrocarbon pesticides as DDT, Aldrin/Dieldrin, and Heptachlor. (Alley Testimony at 4). Research performed by USDA and others has shown that as much as 50% of the original Mirex that was applied in 1962 was recovered from soil residues twelve years after treatment. . . .

Bioconcentration. Unlike most chemical compounds (Livingston Testimony (II) at 1), Mirex continues to accumulate to higher and higher levels in the brain, muscle, liver, skin, and subcutaneous tissues of mammals to which it is fed as a constant increment of the diet, apparently without reaching a plateau. There appears to be an unlimited capacity for accumulation of Mirex in some animal tissues, and Mirex can accumulate in vertebrate animals to extremely high levels. (Gibson Testimony at 3; Gibson TR 157, 165, 168).

Moreover, Mirex accumulates in wildlife and the food of wildlife, including Crustaceans, . . . Ciliate protozoa, ...and algae. . . . At even the most primary trophic levels in the environment the bioconcentration of Mirex has been demonstrated, often at levels thousands of times that found in aquatic media.

In addition, Mirex is highly resistant to metabolic attack, and as a consequence is apparently not eliminated from vertebrate bodies as a result of metabolic conversion . . . nor is it readily excreted through normal excretory channels. . . . However, Mirex can be excreted through special mechanisms, such as lactation and via egg yolks. (Reference 4 at 5-7; Kimbrough Testimony at 9). The significance of these special pathways of Mirex elimination is two-fold. First, man is a consumer of products which are the vehicles of such special elimination in other species. Second, since it has been shown that cows will eliminate significant quantities of Mirex in their milk, it is reasonable to expect that Mirex will also be excreted in the milk of female human beings and thus transmitted to their offspring via breast feeding. . . .

Mirex is transferred through the placenta in rates. The placenta constitutes a barrier between the fetus and the mother which is designed to protect the fetus. Dr. Renate Kimbrough characterized the finding in rats as a "warning signal" that it may also take place in human beings. (Kimbrough Testimony at 12).

Biomagnification. Mirex biomagnifies in higher-level organisms as it moves up the food chain to man. . . . Mirex's great persistence in the environment and its propensity to bioaccumulate and biomagnify mean that even though it is applied at relatively small application rates, it will be available for consumption by humans, wildlife, and marine and aquatic organisms for a long period of time. (Alley Testimony at 4; Plapp Testimony at 10-11).

Non-target insects. Tests have shown that one application of 0.018 pounds of technical Mirex per acre reduces the population of carabid and staphylinid beetles by 60 percent and 67 percent respectively, (Hensley TR2,727). These insects are among the natural predators of the sugarcane borer. (Hensley Testimony at 3).

Mirex leaches from Mirex bait into sea water. (Tagatz Testimony at 5: Reference 11 at 4). Mirex can be leached from Mirex bait by fresh water, and it can thereafter enter a salt water environment. (Tagatz Testimony at 5). Studies have shown that Mirex residues in water resulting from fresh water runoff after application of Mirex in the watershed range from 0.1 to 1.0 parts per trillion in fresh runoff waters. (Alley Testimony at 7-8). Mirex is transported into aquatic organisms, including edible fish, from nearby treated lands. (Duke Testimony at 7, Duke TR 1,901).

Additionally, field studies demonstrated that mirex moved from treated land to estuarine biota after application of mirex bait to the Mississippi watershed and mirex was detected in streams after heavy runoff (Tagatz et al. 1976). Mirex was also detected in fish samples from Lake Ontario in Canada, where it was never registered for use (Kaiser 1974). In upper New York State, from 0.01 to 3.16 ppm mirex residues were detected in waterfowl.

The effects of mirex on birds received little attention until 1977 when mirex was aerially applied to a game management area in Hampton County, South Carolina. In adipose tissue of bobwhite quail, mires residues showed up to a five-fold increase within the first month and peaked in the spring following the mirex treatment, corresponding with insect emergence (Kendall et al. 1977).

In addition, a study found that lesions produced in the livers of chicks "appeared to be related to mirex treatment" (Davison et al. 1976). This find was significant because lesion development was proportional to mirex ingestion and represented irreversible cellular damage.

Humans were not exempt from mirex residues. In 1967, EPA analyzed samples of adipose tissues from persons living in mirex-treated areas and found that the percentage of residues increased in states that had heavy mirex treatments. Forty-four percent of persons tested in Mississippi showed positive residues of mirex compared with traces in South Carolina. The average residue was 0.16 ppm with the range from trace to 5.94 ppm. Twenty-one percent of all samples were positive for mirex (Kutz et al. 1974).

The finding of residues in humans plus laboratory evidence of carcinogenicity prompted the EPA in December 1976 to conclude that mirex posed a carcinogenic risk to humans. Further studies showed that mirex and kepone behaved similarly in (1) resistance to metabolic attack, (2) failure to be eliminated through normal excretory channels, and (3) induction of hepatocellular carcinomas in mice and rats.

With no mirex for aerial application against the IFA in 1978, for the first time since 1960, the Office of Management and Budget reduced the IFA appropriations from $9 million to $900,000. Congress then appropriated $959,000 in FY 1978 for methods development and monitoring activities, $1 million for quarantine, and approximately $4,460,000 for IFA control.

FERRIAMICIDE

Ferriamicide is mirex that degrades. By adding an amine [Keramine T 1902D] (1.7%), ferrous chloride hexahydrate to enhance degradation of the toxicant mirex (0.2%), and soybean oil (8%), and 0.05% mirex, ferriamicide is mirex transformed into a different compound. The distinction between mirex and ferriamicide appears to be a matter of 0.025% mirex. When mirex was phased out, the 1976 EPA notice listed ten registrations of mirex. Four of these were for the IFA:

Mirex 4X - 0.3% mirex (at 10 lbs/acre = 13.62 grams per acre)

Mirex 10:5 - 0.1% mirex (at 1 lb acre = 0.454 grams per acre)

0.15% mirex

0.075%

Ferriamicide is:

0.05% mirex (at 1.5 lbs/acre)

0.05% mirex (at 1 lb/acre = 0.227 grams active ingredient per acre)

0.05% mirex (at 0.75 lbs/acre = 0.171 grams active ingredient per acre)

0.025% mirex at 0.25 lbs/acre

The distinction between the mirex and ferriamicide formulations appears to be 0.075% mirex and 0.05% mirex (mirex at 0.1% at 1 lb/acre uses 0.454 grams per acre, while ferriamicide at 0.05% mirex, at 3/4ths of a pound per acre, uses 0.171 grams per acre).

Initially ferriamicide was developed to prolong the use of mirex (Report of congressional phone call, 8/31/76, from Sam Thompson to D.A. Lindquist, re: "Cooperative agreement on increasing rate of Mirex degradation, Mississippi State Chemical Laboratory."). It was believed that a 400% reduction in mirex dosage would be adequate for fire ant control.

When Mississippi learned about ferriamicide, they applied for a Section 18 (emergency exemption) to use the compound. Due to political pressures and "the need to obtain matching funds from their own legislatures . . . before they recess for the year" (February 22, 1978, letter by Barbara Blum, EPA), EPA approved the ferriamicide request despite its admission that

> There has not been enough time to develop the data on mammalian toxicity necessary to demonstrate human safety, nor have questions been answered about degradation products and persistence in the field. Despite apparently rapid breakdown and reduced shell fish toxicity, we cannot say that ferriamicide is or is not safe for humans, domestic animals and non-aquatic species. It will take up to 36 months to fill the data gaps completely; a conditional registration is possible in 12 months if pending legislation giving the agency authority for such registration is enacted (Butler 1978).

Ferriamicide was allowed only for mound treatment in Mississippi until July 30, 1979. By the time a renewal request would have been required to extend the emergency permit, kepone had been found in ferriamicide shelf samples (see Table 3).

AMDRO® 217,300

In 1979, EPA approved aerial application of a new substance to combat the IFA-- Amdro, manufactured by American Cyanamid. Amdro

> is an amidino-hydrazone compound that is a slow acting stomach insecticide. The toxicant degrades rapidly in the environment in sunlight with a half life of less than 24 hours. It is insoluable in water but is soluable in acetone, methanol, ethanol, isopropanol and hot ethyl acetate. AC 217,300 reportedly does not leach in the soil and is degraded by microorganisms. It apparently does not bioaccumulate in the environment according to model laboratory studies. . . . After four years of testing, Amdro has been shown to be an effective toxicant against the imported fire ant (USDA 1981).

CONCLUSION

Chemical control of the IFA is a profitable market. Table 1 shows how appropriations increased from \$2.4 million in 1958 to \$9.5 million in 1977. The years 1978 to 1980 saw no aerial applications for IFA control and fewer dollars were appropriated. In 1981 aerial registration for Amdro was approved and \$6 million were appropriated-- this from a budget-conscious Congress. However, in such large programs, dollars should not be a key issue. The environmental implications of a control program for the IFA are great. Comprehensive management strategies are needed, not just large-scale chemical applications. The Audubon Society agrees with Homer Collins, a USDA scientist who said, "not enough research attention has been given to mound application treatments for fire ant control" (USDA Fire Ant Work Group Meeting, December 5, 1978, Memo December 15, 1978, p. 3). More dollars need to go to research to develop effective chemicals, juvenile hormones, insect growth regulators, and chitin inhibitors for mound treatment.

The Department of Interior, commenting on USDA's Final Programmatic EIS (May 21, 1982), criticized the USDA for continuing to dwell "almost entirely on aerial application over large acreages and this mode of application causes great concern for almost all forms of aquatic animal life" (FEIS 1981). Von Rumker et al. (as referenced in Shoemaker and Harris 1974) estimated that less than one percent of insecticide applied by air is absorbed by insects through contact, inhalation, or ingestion. Himel (as referenced in Shoemaker and Harris 1974) described the present system of crop spraying as "the most inefficient industrial process ever practiced." Clearly, we cannot afford environmentally to spray areas millions of acres of coastal wetlands, salt marshes, wildlife refuges, and river areas for IFA; we also cannot afford to use scarce public funds for such an expensive and inefficient program. Perhaps more dollars and effort should concentrate on mound application compounds, because the mound is the source of the problem. Another concern in any mass spray program is pesticide resistance by other organisms and this concern should be realistically addressed in any large spray program.

The risks of pesticides cannot be disregarded. Steps have been made to make chemical registration and use safer; however, the quantity of pesticides produced increased 80% in the 1970's. They doubled since Silent Spring. In the U.S. they will double in the next 20 years and quadruple in developing countries. As long as chemicals must be used to protect our food sources and ourselves, risk to the soil, non-target species, and humans abounds.

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Table 1. Estimated acres of IFA infestation, federal IFA appropriations, and control monies (from USDA June 2, 1982) (in thousands).

Year	Infested Acres (Est.)	Federal Control	State & Local Coop. Funds	Total Control	Actually Spent By APHIS[a]	Appropriations
1932	200					
1947	2,000					
1954						
1955						
1956						
1957						
1958		736	1,506	2,242	2,088	2,400
1959	26,000	1,269	2,302	3,571	2,437	2,486
1960		1,550	1,844	3,394	2,610	2,495
1961		1,465	1,420	2,893	2,546	2,571
1962		1,392	1,343	2,735	2,529	2,571
1963	31,000	1,689	1,735	3,424	2,967	2,610
1964		1.258	1,896	3,154	2,446	2,495
1965		1,764	1,864	3,628	2,977	3,270
1966		2,106	2,076	4,182	3,910	3,303
1967	106,000	2,835	2,002	4,837	3,249	5,389
1968		3,280	3,524	6,804	4,530	4,809
1969		2,839	3,730	6,569	4,595	5,036
1970		2,843	3,720	6,563	5,295	5,643
1971	126,500	2,533	4,271	6,804	6,361	7,762
1972		2,587	4,671	7,258	7,108	7,552
1973		4,519	3,533	8,052	7,047	7,928
1974		3,916	5,696	9,612	7,180	7,195
1975[b]	135-150M	4,233	4,812	9,045	8,708	9,037
1976		3,253	2,184	5,437	8,545	9,127
1977		3,299	3,770	7,069	6,823	9,487
1978	190,000	584	4,710	5,294	3,529	1,942
1979		2,467	1,394	3,861	2,467	1,942
1980		2,000	1,315	3,315	4,303	1,996
1981	230,000	2,800	2,650	5,450	3,852	6,000
		67,217	67,968	125,193	108,102	115,046
1982						5,915
						120,961
1983[c]						

Estimates 1932-71: National Academy of Sciences
Estimates 1975: CAST
Estimates 1978: Texas A & M Booklet

[a] Appropriated and used for survey, regulatory activities, environmental monitoring, control eradication, and method development work, including field tests for evaluating controls.

[b] FY 1975-1976 includes a transition quarter for the period 7/1/76 - 9/30/76 to new fiscal year beginning 10/1/76.

[c] 1983 appropriation of $2,625,000 is pending approval of Congress.

Table 2. Summary of pesticides used and federal action taken for IFA.

Year	Pesticide	Federal Action
1920	calcium cyanide gasoline	
1946	chlordane	
1957	heptachlor dieldrin	Congress appropriated $3 million. Only a few states appropriated funds at first (Alabama, Georgia, Louisiana and Florida).
1958	2 lbs/acre	Federal quarantine established in nine southern states.
1959		Alabama stopped matching funds. USDA offered heptachlor free to Texas landowners who signed release absolving federal, state and local government of responsibility for damage.
1960	heptachlor 1-1/4 lbs/acre	FDA cancelled tolerances for heptachlor residues on pasture grasses. (Texas and Florida also withdrew financial support for IFA program.)
1962	mirex 10 lbs/acre	
1963	mirex 2-1/2 lbs/acre	
1964		GAO (Government watchdog agency) accused USDA of disregarding scientific opinion and wasting government funds. Whitten overuled ARS budget cut request. Budget Bureau pressuring reduction in budget.
1965	1-1/4/acre twice/year	
1967		President Johnson eliminated program for FY 1967. Whitten increased appropriation. Johnson froze $2 million of the $5 million budget funds. USDA asked NAS for report which concluded eradication not biologically or technically feasible. IFA dramatically spread, IFAs not caused significant harm to land values, agricultural production or health.
1970		Pesticides transferred from USDA to EPA. Interior Secretary Hickel removed Interior land from mirex applications because of harm to fish.
1971		Approximately $800,000 diverted to extramural research and apportioned via specific cooperative agreements to various scientists at universities in the south. (Lofgren, Tall Timbers Conference paper at 2.)

Table 2. Continued.

Year	Pesticide	Federal Action
1972		National Academy of Sciences Report: mirex poses serious risk to aquatic life, particularly young shrimp and blue crabs.
1973		3/28/73-EPA prohibits aerial applications to coastal counties, broadcast applications on aquatic areas and heavily forested areas.
		4/4/73-EPA Notice of Intent to hold a hearing.
		7/11/73-Hearings began, continued until 3/28/75 when Allied Chemical Company withdrew from negotiations, and announced cessation of production of mirex until agreement reached.
1977	mirex phased out	6/28/77-USDA said program not as effective as previously, because any individual who does not want mirex can request land not be treated.
	ferriamicide EUP	9/29/77-EPA issued experimental use permit for ferriamicide to Mississippi for Florida and Mississippi 9/9/77 to 10/1/78.
		12/16/77-Mississippi applied for emergency exemption for aerial application of ferriamicide.
		12/31/77-Mirex no longer legal by aerial application mound and ground broadcast permitted through 6/30/78.
1978	ferriamicide Sec. 18 Emergency Use	OMB reduced appropriations from $9 million to $900,000 because "like pouring money down a rat-hole." Treatments only in Mississippi, Alabama, and Georgia. Rest of states decided not to treat.
		3/8/78-EPA approved emergency exemption 7/1/78 to 6/30/79.
1979	Amdro EUP	House of Representatives defeats amendment to allow emergency use of mirex for two years by vote of 224 to 167 (11/28/79).
1980	Amdro conditional registration	Senator Talmadge directs EPA and USDA to develop a comprehensive strategy.
1981	ferriamicide request for conditional registration	

Table 3. History of chlordecone.

Year	Action
1960	First bait experimented with for the IFA was chlordecone (Kepone) in peanut butter. Mirex, an analogue of chlordecone, developed.
1974	G.W. Ivie (Dorough and Alley) report that mirex converts to chlordecone.
1976	USDA reported chlordecone as degradate of mirex.
	EPA finds chlordecone in mothers milk in the south.
	NCI concludes chlordecone is carcinogenic in both sexes of rats and mice. (Induces statistically significant numbers of hepatocellular proliferative lesions, including hepatocellular carcinomas.) (January, 1976)
	Mirex samples taken from Mississippi production plant contained chlordecone at levels between 0.25 ppm and 2.58 ppm. (Pesticide Toxic Chemical News, July 28, 1976)
	Alley and Layton present paper to the American Chemical Society concluding that "direct photochemical chlordecone reactions are not a major route for the conversion of mirex to chlordecone." (paper at 3)
6/17/76	EPA notices intent to voluntarily cancel all registered products containing chlordecone. Final cancellation takes effect May 1, 1978.
4/6/78	Memo from the National Program Staff of notification from J.H. Ford Laboratory Director of National Monitoring and Residue Analysis Lab that as much as 22 ppm chlordecone was found in 54-day samples of ferriamicide bait samples formulated at the Prairie, Mississippi Plant.
4/14/78	Memo from Dr. Williamson, APHIS, on report of shelf-life study of ferriamicide bait samples. Fifty samples were analyzed for mirex, photodegradative studies and chlordecone. They were divided into four categories. All ten samples of the Series I, Day 54, bait samples had chlordecone and eight had detectable 8-monohydromirex or photomirex.
	Dr. Alley in the conversation following this discovery, told of his finding that between 3-6% chlordecone was formed from the degradation of technical mirex in the bait formulation. Added that "methanol or ethylene glycol would dissolve the aliphatic amine, which will inhibit the production of chlordecone in the mirex degradation process."
4/25/78	APHIS IFA Technical Work Group Meeting, discussed finding of chlordecone as degradation product of ferriamicide, which "has resulted in considerable confusion in evaluation."

APPENDIX E

FERRIAMICIDE: A TOXICOLOGICAL SUMMARY

Earl L. Alley

PANEL IV

The following summarizes the discussion on the toxicological properties and composition of ferriamicide. It is believed that aerial broadcast of ferriamicide shows promise for effective IFA control. Aerial broadcast application increases the effectiveness of ferriamicide bait or other insecticidal baits and offers more complete coverage than mound application; therefore, reinfestation rates are reduced. Table 1 compares the large amount of toxicant required for individual mound treatments versus that required for broadcast treatments with baits. Broadcast application of ferriamicide requires only 227 mg of active ingredient per acre, but drenches of individual mounds require 400 to 30,000 mg per mound. Table 1 also shows that the amount of toxicant needed for IFA control has been reduced from 50,000 mg per acre for dieldrin/heptachlor to the 227 mg recommended for ferriamicide.

Table 2 describes the composition and function of the compounds in ferriamicide. The amine and ferrous chloride components reduce the half-life of mirex from 12 years to about 0.15 years. Additionally, propylene glycol suppresses the production of kepone.

During the discussion, the structure and numbering system for mirex and its mono- and dihydrogen derivatives were shown and the UV spectrum of mirex, triethylamine, and the charge-transfer complex were described. The relationship between wavelengths of sunlight at the earth's surface, the photo-chemical stability of mirex, and the photo-chemical reactivity of ferriamicide also were explained. The absorption by ferriamicide bait at wavelengths greater than 300 nm produces a dramatic increase in the degradation rate of the active ingredient. The dechlorination reactions of mirex photo-chemistry in ferriamicide leads mostly to substitution at the 10 position. This is important because some of the 10-substituted derivatives are labile metabolically; because of the greater polarity of the derivatives, one might expect lesser problems with bioaccumulation and biomagnification.

Field degradation studies on a 300-fold treatment over normal application rates showed that after 15 weeks, about 75% of the mirex in ferriamicide baits had degraded. After three years, only about 20% was left. One plot located in a shaded area showed slightly less degradation than a plot in full sunlight.

Table 3 is an analysis of the degradates from the field test described above. Normal application rates produced residues that were too small to be determined by electron capture techniques. The compounds were confirmed by two column capillary techniques, yet two were misidentified (chlordecone and 8,10-*syn*-dihydrogen isomer). This was shown by comparing authentic standards of negative ion chemical ionization spectra with these samples. This points out the problem that arises when identities of compounds have been established by comparing gas chromatography retention times only. It is possible, therefore, that many of the data reported in residue monitoring of wildlife and humans may be similarly misidentified. This is of particular concern at concentrations near the detection limit of the technique.

There has been some controversy over the toxicity of photo-mirex and mirex. Canadian workers had reported that photomirex was 10 to 100 times more toxic than mirex. However, a pathologist from the EPA Pesticide Scientific Advisory Panel found no quantitative differentiation between the toxicities of mirex and photomirex. It is believed that the Canadian test materials were impure.

The amount of mirex applied throughout all the control programs was 450,000 kg. As a fire retardant, 1,000,000 kg of mirex has been used. When using ferriamicide, the entire IFA infested area would have to be treated ten times to use the same amount of mirex (450,000 kg). At maximum foreseeable rates of use, this would take about one hundred years (23,000,000 acres per year).

Perhaps this 450,000 kg, a portion of the 1,000,000 kg used in plastics, and the contamination of Lake Ontario is what produced the residues observed in humans and animals. That the human residues reported by Kutz may have resulted from less than part per billion levels of residue in food was deduced when extrapolations from animal studies were made assuming a five-year exposure. These levels are hundreds of times less than those in test animals for which toxicological effects have been observed.

Table 4 lists the positive and negative aspects of the mirex active ingredient in ferriamicide. It is believed that the hazards evident from toxicological results are mitigated by the low exposure expected for humans. Ferriamicide helps solve several of the problems encountered with the use of mirex, such as biomagnification, persistence, lack of metabolism, and kepone production, because it promotes degradation to compounds whose chemical and physical properties lessen the problems associated with these parameters. (For in-depth toxicological information, see Table 5.)

In conclusion, ferriamicide is a much more cost effective approach to the fire ant problem than other currently available methodologies. The effectiveness of this or other baits is increased by aerial broadcast application, because the more complete coverage reduces reinfestation rates.

Table 1. Chemical control of IFA.

Chemical	mg AI/acre
dieldrin/heptachlor	> 50,000
kepone	2-6,000
mirex 4X	1,700
mirex 2X	850
mirex 10/5	454
ferriamicide	227
Amdro	4,000
drenches	400-30,000/mound

Table 2. Ferriamicide bait composition and function.

Substance	Use
corn cob grit	carrier
soybean oil	attractant
mirex (0.05%)	toxicant
Kemamine T1902D	degradation enhancer
ferrous chloride	degradation enhancer
citric acid	antioxidant
propylene glycol	solvent-kepone inhibitor

Table 3. Field degradation of ferriamicide.

Compound	ppm	Confirmation
mirex	0.052	yes
10H	0.006	yes
8H	0.010	yes
5,10A (trans)	0.005	yes
5,10B (cis)	ND	yes
8,10A (anti)	0.037	yes
8,10B (syn)	0.289	no (det. 0.001)
kepone	0.023	no (det. 0.001)
2,8	0.069	yes
3H, 4H, etc.	0.129	?

Table 4. Pros and cons of mirex.

Pro	Con
efficacious	biomagnifies
low rates	bioaccumulates
bait—targets toxicant	no metabolism
broadcast application	degrades slowly
human exposure low	residues in wildlife
wildlife—nontoxic	chronically toxic
low residues in human food	liver damage
not genotoxic	possible carcinogen
adsorbs to clay	crosses placental barrier
	fetal toxicity

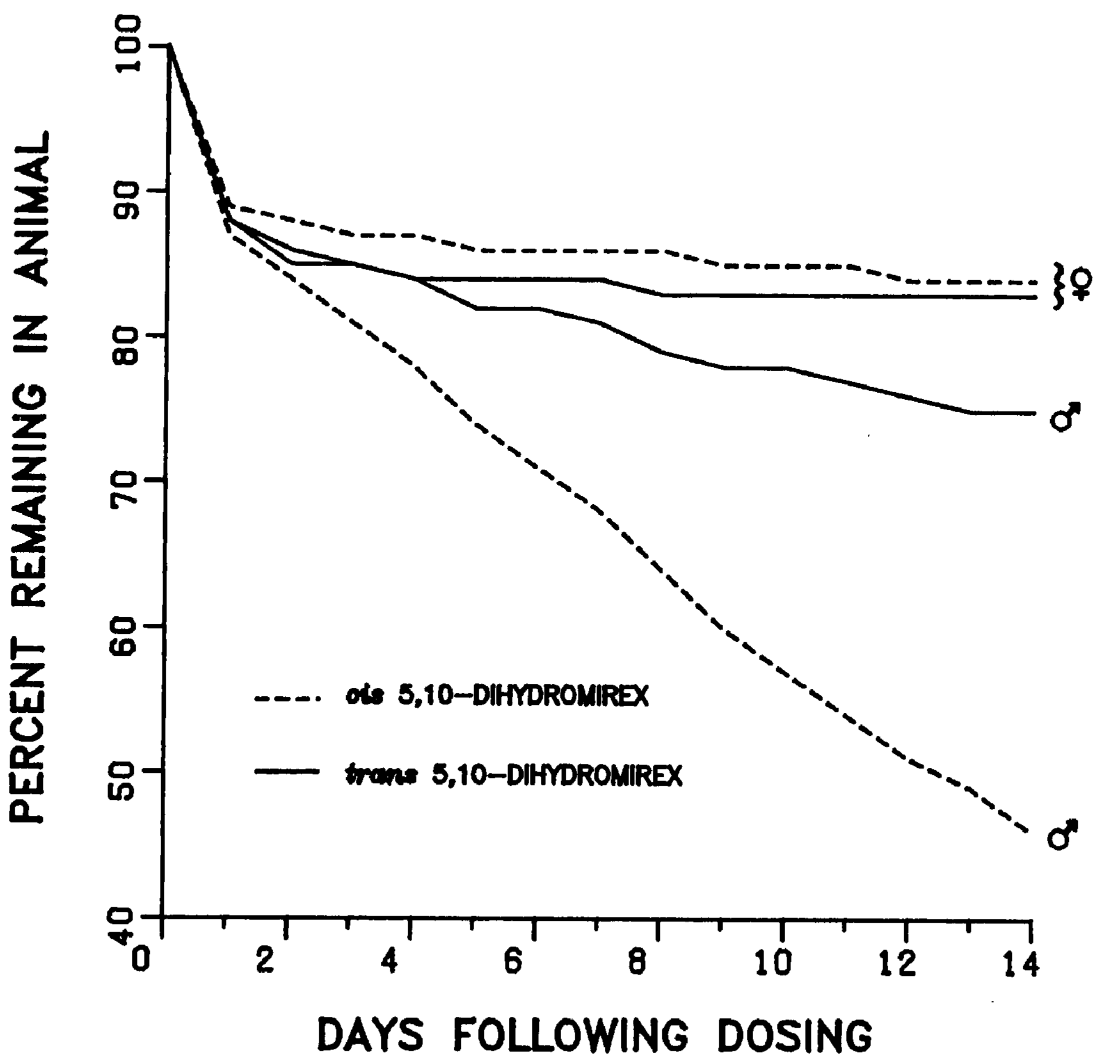

Figure 1. Percent of radioactivity remaining in rats following a single oral dose of ^{14}C-radiolabeled compound (days 1-6: mean of 12 animals; days 7-14: mean of 6 animals).

Table 5. Toxicology summary of ferriamicide.

ACUTE TOXICITY[1]

oral LD_{50}	rats	312 mg/kg
dermal LD_{50}	rabbits	> 2000 mg/kg
eye irritation	rabbits	data not presently available
skin irritation	rabbits	data not presently available
skin sensitization	guinea pigs	data not presently available
inhalation LC_{50}	rats	data not presently available

SUBCHRONIC TOXICITY[1]

28-day dietary study on Sprague-Dawley rat

dose levels (ppm):	0.0	0.5	5.0	50	75
biochemistry:					
p450	ne	dec	inc	inc	inc
liver SDH	ne	inc	inc	inc	inc
histopathology:					
liver	ne	ne	inc	inc	inc
thyroid	ne	ne	ne	ne	inc

90-day dietary study on Charles River rat

dose levels (ppm):	0	5	20	80	320	1280
mortality:						
male	ne	ne	ne	ne	ne	inc
female	ne	ne	ne	ne	inc	inc
hemoglobin	ne	ne	ne	ne	dec	dec
white blood cells	ne	ne	ne	ne	ne	inc
urinalysis	ne	ne	ne	ne	ne	ne
body weight	ne	ne	ne	ne	dec	dec
liver weight:						
male	ne	ne	ne	inc	inc	inc
female	ne	ne	ne	ne	inc	*
histopathology	ne	ne	ne	inc	inc	inc

[1] Mirex active ingredient
[2] no dose response

ne = no effect
inc = increase
dec = decrease
SDH = Sorbitol Dy Hydrogenase

Table 5, continued

90-day dietary study on beagle dog

dose levels (ppm):	0	4	20	100
mortality:				
male	ne	ne	ne	inc
female	ne	ne	ne	inc
alkalin phosphatasae blood	ne	ne	ne	inc
liver weight	ne	ne	ne	inc
spleen weight	ne	ne	ne	inc
histopathology	ne	ne	ne	ne

CHRONIC TOXICITY[1]

2-year dietary oncogenicity study on mouse (18 males, 16 females/test group)

dose levels: 10 mg/kg/day (7-28) by gavage; then 26 ppm

mortality: all animals before 18 months

histopathology: significant increase in hepatomas

2-year dietary oncogenicity study on Charles River CD rat (26/test group)

dose levels (ppm):	0	50	100
histopathology:	ne	inc	inc

2-year dietary oncogenicity study on rat (report due approximately six months)

dose levels (ppm)	0	0.5	-	50

3-generation reproduction study on prairie vole

dose levels: varied from 0.1 to 25 ppm

results: difficult to evaluate due to protocol deficiencies and statistical inaccuracies

Table 5, continued

TERATOGENICITY[1]

Study on Wistar rat

dose levels (mg/kg/day):	0.0	1.5	3.0	6.0	12.5
toxicity (male)	ne	ne	inc	inc	inc
deciduoma	ne	ne	ne	ne	inc
death (female)	ne	ne	ne	ne	inc
weight (female)	ne	ne	ne	ne	dec

Study on CD rat

dose level:	10 mg/kg (single or during 4 days)
effect:	cataracts in neonates
note:	toxicity, not teratogenicity

Study on pregnant CD rat

dose level:	dietary 25 ppm
effect:	neonatal liver enzyme induction of p-nitroanisole and aminopyrine demethylase

MUTAGENICITY[1]

Ames test (salmonella)

mirex	negative
8-monohydro (photomirex)	negative
10-monohydromirex	negative
5,10-dihydromirex	negative
2,8-dihydromirex	negative

Hepatocyte primary culture on human cell — negative

hypoxanthine: guanine phosphoribosyl transferase assay

Dominant lethal assay in rats

dose levels (administered 10 days prior to mating):

mg/kg/day	0.0	1.5	3.0	6.0[3]
viable embryos/ pregnancy	ne	ne	ne	ne
deciduomas/ pregnancy	ne	ne	ne	ne
pregnancy/mating	ne	ne	ne	dec[4]

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[3]one death

[4]one trial

Table 5, continued

WILDLIFE AQUATIC TOXICITY[1]

Static 96-hour LC_{50} (vertebrates)

channel catfish	> 100 ppm
bluegill sunfish	> 100 ppm
rainbow trout	> 100 ppm

Dynamic Toxicity

fathead minnow	50-60 ppm, no effect

Reproduction of fathead minnow

dose levels:

ppb	0	2	3	7	13	34
hatching success	ne	inc	inc	inc	ne	ne
spawn production	ne	ne	ne	ne	dec	dec
egg production	ne	ne	ne	ne	dec	dec

mirex accumulation factor: 28,000

elimination rate: 54% at 56 days in mirex-free water

Static 96-hour LC_{50} (invertebrates)

daphnia	> 100 ppm
crayfish	1000-5000 ppm
hydra	4.1 ppm

WILDLIFE AQUATIC TOXICITY[5]

Static 96-hour LC_{50}

vertebrates:	similar to mirex
invertebrates (daphnia):	generally more toxic than mirex
5,10-dihydromirex	0.1 - 3.2 ppm

---

[5] degradates

Table 5, continued

WILDLIFE TOXICITY[1]

Avian Acute Toxicity—Dietary LC_{50} (ppm)

ring-necked pheasant	1540
bobwhite quail	2511
Japanese quail	> 5000
mallard duck	> 5000

Avian Reproduction

bobwhite quail dose levels (ppm)	0	1	20	40
results	no effect at any dose level			
mallard duck dose levels (ppm)	0	1	100	
results	ne	ne	ne[6]	
herring gull egg dose levels:	doses injected into eggs at natural levels			
results	no effect on hatchability or chick survival			
Japanese quail	dosed with radiolabeled ^{14}C-Mirex			
excretion	85% by 84 days			

CONCLUSION: Mirex poses low risk for effects on avian populations.

---

[6] moderate reduction in duckling survival

METABOLISM

SINGLE ORAL DOSE EXCRETION: ^{14}C-RADIOLABELED COMPOUND

Compound	Time (days)	% Excreted Total	% Excreted Urine
Mirex	14	32	0.4
8-monohydro	28	50	neg
10-monohydro	-	-	-
2,8-dihydro	14	19	0.1
5,10-dihydro			
cis	14	54	15
trans	14	25	4
5,8,10-trihydro	6	32	6

Table 5, continued

CHRONIC TOXICITY[7]

21-month dietary study of Sprague-Dawley male rat (10 animals/dose group)

dose levels (ppm)	0.0	0.2	1.0	5	25	125
mortality	ne	ne	ne	ne	ne	inc
liver weight	ne	ne	ne	inc	inc	inc
liver SDH	ne	ne	ne	ne	inc	inc
histopathology	statistical significance not reported					

SUBCHRONIC TOXICITY[7]

28-day dietary study on Sprague-Dawley male rat, 8-monohydromirex

dose levels (ppm)	0.0	0.5	5.0	50	75
liver weight	ne	ne	inc	inc	inc
liver SDH	ne	inc	inc	inc	inc
histopathology					
liver	ne	ne	ne	inc	inc
thyroid	ne	ne	ne	ne	inc
liver p450	ne	ne	inc	inc	inc

90-day dietary study on Sprague-Dawley male rat, 8-monohydromirex

dose levels (ppm)	0.0	0.2	1.0	5	25	125
mortality	ne	ne	ne	ne	ne	inc
liver weight	ne	ne	ne	inc	inc	inc
histological	ne	inc	inc	inc	inc	inc

[7] 8-monohydro (purity of test compound questionable)

APPENDIX F

A BRIEF OVERVIEW OF THE REQUIREMENTS FOR PESTICIDE REGISTRATION

D.J. Severn

PANEL IV

The following briefly reviews the requirements for pesticide registration as they relate to environmental toxicology, and summarizes how information submitted under these requirements, together with available monitoring, is used to prepare assessments of exposure of humans and the environment to pesticides.

REQUIREMENTS FOR REGISTRATION OF PESTICIDES UNDER THE FEDERAL RODENTICIDE ACT (FIFRA)

*Registrants must bear the burden of demonstrating the safety of their products. To do this they submit testing data to EPA, which generally includes product chemistry, environmental chemistry, toxicology, and ecological effects data.

*EPA's registration guidelines specify the types of data required to be submitted. These test requirements are *use-pattern dependent*; for a broadcast application of a pesticide formulated as a bait, the following types of data are generally required:

product chemistry: identity and composition of the product, physical and chemical properties, analytical methods

environmental chemistry: degradation, environmental metabolism, mobility, and overall dissipation studies

toxicology: acute oral, dermal, and inhalation studies; teratology and reproduction studies; long-term feeding studies

wildlife and aquatic organisms: acute avian and aquatic organism tests; other tests depend on results of these.

Once submitted to EPA, the data are reviewed for scientific quality and utility by scientists in the Office of Pesticide Programs (OPP). These reviews are used in making decisions to grant registration under various conditions, to require further studies, or to waive additional requirements. The registration guidelines allow maximum flexibility in carrying out the required studies and are meant to guide the generation of the particular set of data needed to make the findings required by FIFRA for registration.

For pesticides registered in the last few years, these data are generally available. Older pesticides, however, often have less data available; reregistration procedures underway in OPP will require the missing data to be submitted.

EXPOSURE AND RISK CONSIDERATIONS

FIFRA requires EPA to determine what pesticides will perform their function without unreasonable risks to man or the environment. Thus, an assessment of the likely risks of pesticide use is made during the course of approval of registration. This assessment utilizes the data described above.

Risk assessments require not only an understanding of the toxicology of a pesticide but also an evaluation of the extent to which man and the environment may be exposed to the pesticide. Information on environmental transport and fate, generated according to the guidelines described above, provides a substantial basis for this evaluation. However, the question of direct or indirect human and environmental exposure to a pesticide often arises. Assessment of human exposure requires detailed information about actual use practices, normal human activities at treated sites, and some measure of the likelihood of actual transfer to and absorption of pesticide residues in humans. In the past, EPA used information on dermal, inhalation, and dietary exposure to arrive at estimates of the total exposure likely to arise from the use of a pesticide.

For pesticides applied for fire ant control, very little information has been available to estimate exposure of either applicators or the general public. While methods of monitoring direct exposure have been developed and extensively used to measure exposure resulting from other types of pesticide use (Davis 1981), field measurement of exposure to bait formulations has not been carried out. The exposure of people living in areas treated for fire ant control is likely to be very low, and the routes of exposure to the bait after application are not clear. Field studies, perhaps using novel methods of measurement, are needed to define the routes and extent of exposure.

Another approach to measuring exposure involves the monitoring of human urine, blood, or adipose tissue samples. The presence of pesticide residues in human tissue provides direct evidence of exposure, although it does not define the route of exposure. EPA has for several years carried out monitoring surveys for organochlorine pesticide residues in human adipose tissue samples. When mirex was first detected in these samples (Kutz 1974) a more extensive survey was carried out in eight southern States in 1975 to 1976 (EPA 1980). A total of 624 adipose tissue samples were analyzed; 23% contained detectable levels of mirex. A distribution of the positive samples is given in Table 1.

Mirex, a lipid-soluble material, is efficiently bioconcentrated in mammalian tissues. While these results do not identify the actual pathway of exposure, they do demonstrate that people were exposed to mirex from its use as a fire ant control pesticide.

Table 1. Distribution of positive samples of mirex in adipose tissue.*

State	Zero	Positive	Total	Percent
Alabama	36	3	39	7.7
Florida	129	8	137	5.8
Georgia	72	19	91	20.9
Louisiana	83	46	129	35.7
Mississippi	73	63	136	46.3
North Carolina	18	0	18	0.0
Texas	38	0	38	0.0
South Carolina	34	2	36	5.6
TOTAL	483	141	624	22.6

*Analyses were electron-capture gas chromatography; approximately 10% of the positive samples were confirmed by mass spectrometry.

EPA also conducted a nationwide survey (Savage 1981) of organochlorine pesticide residues in human breast milk. Mirex was not detected in any of the 1436 samples analyzed.

USDA has carried out extensive monitoring surveys for mirex in various components of the environment. A survey of mirex residues in meat and milk of cows grazing in areas treated with mirex found no detectable mirex in milk but did detect mirex in meat.

In summary, FIFRA requires that the risks of the use of pesticides be balanced against the benefits of their uses. Sufficient information on the risks and benefits of pesticide use for fire ant control is needed to arrive at reasonable decisions regarding this use. Clearly, the use of mirex has led to mirex residues in the human population of treated areas in the southern United States.

REFERENCES

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Kutz, F.W., A.R. Yobs, W.G. Johnson, and G.B. Wiersma. 1974. Mirex residues in human adipose tissues. Environ. Entomol. 3:882-884.

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APPENDIX G

ENVIRONMENTAL TOXICOLOGY OF PESTICIDE APPLICATION PROGRAMS

H.N. Nigg

PANEL IV

Most environmental safety decisions are of necessity based on small tests, i.e., acute toxicity to mammals, birds, and aquatic organisms; chronic toxicity, especially mutagenicity, carcinogenicity, teratogenicity; metabolism; persistence of residues; human exposure; and other tests depending on the chemical. Often, however, companies fail to investigate what might be termed the "human side" of chemical use. For instance, what effect does attractive packaging have on children? Does it entice them to test the product? Also, children around 11 years old are generally more sensitive to toxicants. Many of the areas infested by fire ants are also playgrounds, school yards, football fields, etc. Bait should not be attractive to children and the persistence and/or application method should assure that the potential for exposure to children is zero. Migrant workers pose special problems, partly due to their social strata. They may not speak and/or read English. Often their understanding of pesticides is zero. Who takes responsibility for these people for pesticide exposures? These kinds of issues concerning pesticide registration need to be addressed.

When evaluating IFA control programs, the specifics of each suggested chemical or program is the only relevant information. But people may use a program unwisely; unanswered questions and incomplete data can lead to unforeseen problems.

The Environmental Protection Agency should focus on the following three areas when considering a chemical for registration:

1. Environmental Toxicology
   a) toxicity to aquatic organisms. Of particular importance are the effects of insect growth regulator (IGR) compounds on crustacea. IGR compounds also may produce lesions in the insect hormone system as a mode of action. Similar effects may occur in non-target organisms and should be considered when registering these compounds.
   b) toxicity to avian species. The same comments for aquatic organisms hold for avian species. Apart from acute toxicity, effects on reproduc-

tion are particularly important.

2. Toxicant/Acre

   One consideration must be the amount of toxicant per acre necessary to control the fire ant. This may mean that broadcast treatment of large areas by air may result in less environmental contamination than a mound drench. However, mound drench may be more practical around lakes and streams. This consideration should be coordinated with the known toxicology of each compound.

3. Attractiveness of Baits to Non-target Organisms

   This might be accomplished by (1) testing the attractiveness with mice or rats and chickens, and (2) observing treated fields during the experimental use permit stage of registration.

These questions can be answered. Effective and 'safe' materials can be placed on the market now and can be developed for the future. The key is a conscientious recognition that human health and environmental protection have a high priority in developing pesticides for fire ant control.

APPENDIX H

MODELS FOR DECISION-MAKING

John Wood

PANEL IV

Any large-scale program for controlling a pest such as the imported fire ant (IFA) has variable impacts on diverse elements of society. The U.S. Department of Agriculture (USDA), Animal Plant Health Inspection Service (APHIS) program managers must make decisions about the impacts of large-scale projects in the context of available research information, the reality of social and political pressures, and the mandates of legislation. These decisions may be international, national, regional, or local in scope.

Problems in evaluating possible impacts, especially for the long term, often arise because (1) program needs and environmental objectives often conflict, (2) alternative strategies that may arise from research are uncertain, and (3) legitimate concerns by diverse groups may be unknown. Because of these difficulties, long-range planning that satisfies program needs while maintaining a sensitivity to environmental impact is an extraordinarily complex process.

To assist USDA/APHIS in making decisions on pest programs, several computer simulation models for regional and interregional evaluations were developed. Although many models have been developed that deal with the environmental impact evaluation of pesticide use, these models tend to be benefit-cost models, and their use has been designed mainly for pesticide regulation rather than program impact evaluation. Further, they have not used a framework within which the adequacy of an environmental assessment model might be examined. The necessity of examination is motivated by the widespread use of models for predicting environmental consequences of various program activities and by the reliance on these model predictions for deciding whether a particular program complies with regulatory perspectives.

The environmental pesticide decision models developed by APHIS center on a program's environmental situation based on all current knowledge and understanding, both scientific and intuitive. The models were designed for producing defendable assessments of the environmental effects of a pesticide program and are part of a comprehensive APHIS program consisting of: (1) feeding studies, (2) local effects of a pesticide program, and (3) large area effects of a pesticide program. Toxicological data are derived from information developed by registrants, from EPA files, appropriate literature sources, and agency time/dose/response feeding studies. The local effects model and the large area effects model consider seven types of impacts: human exposure, off-site area influence, research area conflicts, rare biota, wildlife, fish, and aquatic forms.

The decision-making process is complex and often must deal with the uncertainties of environmental situations in addition to the social and economic outcomes. The USDA/APHIS computer models improve the ability of pest control program managers to make environmental decisions on large-scale programs.

APPENDIX I

CHEMICALS CURRENTLY UNDER INVESTIGATION FOR POSSIBLE IFA USE

Panel IV

The following summarizes information presented at the IFA symposium by various chemical companies on compounds that are registered, pending registration, or proposed for registration for use on the IFA. The information includes: (1) chemical name and structure; (2) chemical and physical properties; (3) metabolic and environmental degradative fate and pathways, persistence, etc.; (4) toxicity; (5) possible mutagenicity, carcinogenicity, and teratogenicity; (6) use patterns; and (7) proposed label directions. Such information is essential for registration by EPA.

The information presented by the chemical companies includes their own data interpretation; inclusion of these data and interpretations do not imply acceptance by the USDA or the EPA. The use of these new chemicals depends on (1) EPA regulation; (2) efficacy as determined by USDA, state, and other agencies; and (3) the marketplace.

PESTICIDE SUMMARY DATA SHEET
A. MOUND DRENCH

Chemical Name:
diazinon: O,O-diethyl O-(2-isopropyl-4-methyl-6-pyrimidinyl) phosphorothioate

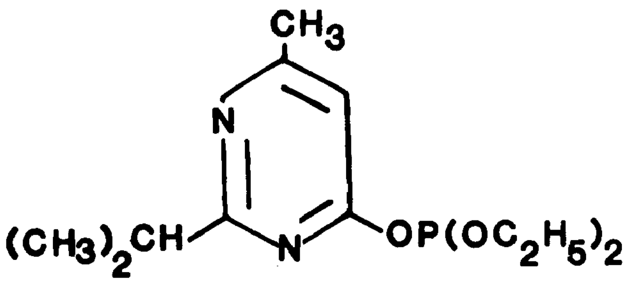
Empirical Formula:
$C_{12}H_{21}N_2O_3PS$

Molecular Weight:
304

Form:
brownish liquid

Odor:
faint garlic

Chemical Structure:

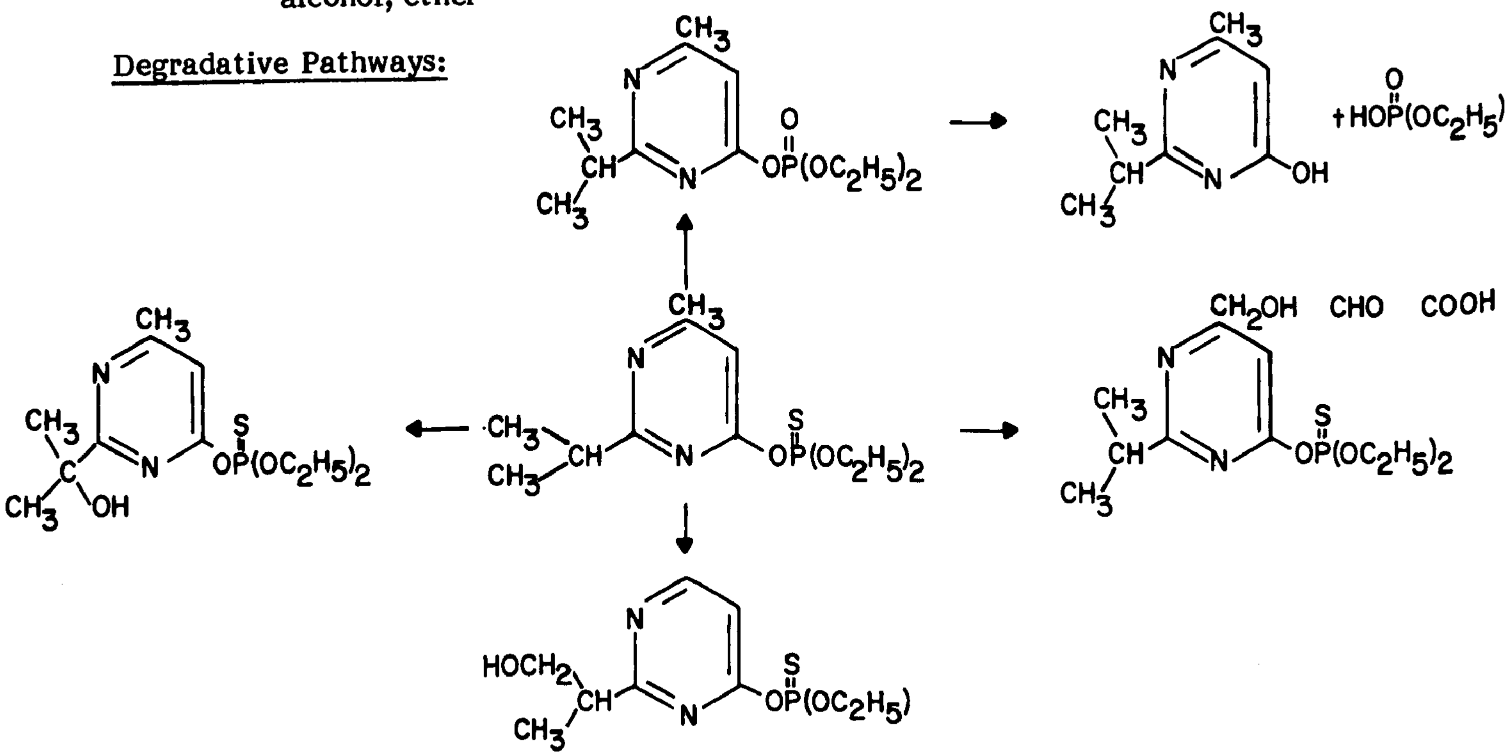


Trade Names:
Diazinon

Chemical and Physical Properties:
b.p.: 83-84 C/0.002 mm Hg   v.p.: 4.1×10^{-4} mm Hg at 20 C

solubility:
H_2O 40 ppm, miscible with benzene, cyclohexane, petroleum ether, alcohol, ether

Degradative Pathways:



Toxicology:

mode of action: irreversible inhibitor of acetylcholinesterase

		LD_{50}
Acute:	rat, oral	76-108 mg/kg
	rat, dermal	1000 mg/kg
	mallard duck, oral	3.5 mg/kg
	pheasant, oral	4.3 mg/kg

		LC_{50}
Acute:	blue-gill	48 h, 0.030 ppm
	rainbow trout	24 h, 0.39 ppm

Uses:

mound drench

Formulations:

wettable powder, emulsive concentrate, microencapsulated

Dosage:

0.5% in water base

PESTICIDE SUMMARY DATA SHEET
A. MOUND DRENCH

Chemical Name:
carbaryl: 1-naphthyl n-methylcarbamate

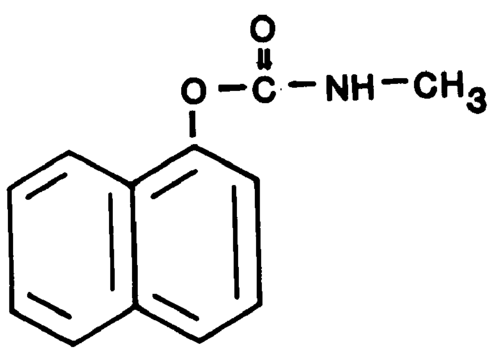
Empirical Formula:
$C_{12}H_{11}NO_2$

Molecular Weight:
201

Form:
tan solid

Odor:
nearly odorless

Chemical Structure:



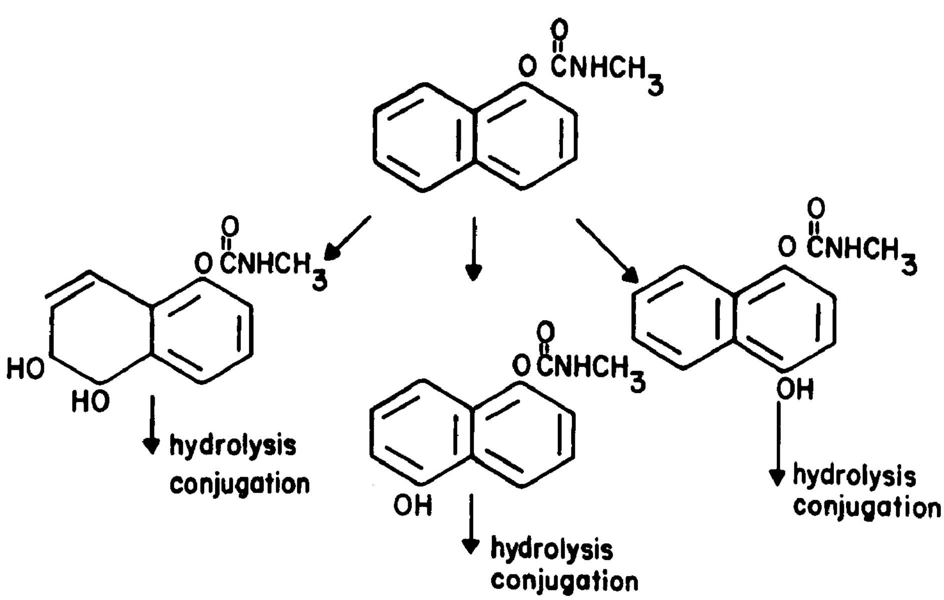
Trade Names:
Sevin, Union Carbide Chemicals

Chemical and Physical Properties:
m.p.: 142 C

v.p.:<0.005 mm Hg at 26 C

solubility:
40 pp

Degradative Pathways:



Toxicology:

acute toxicity:

LD_{50}, rat, oral: 540-800 mg/kg

LD_{50}, rat, dermal: 2000 mg/kg

Uses:

mound drench

Dosage:

1.0-1.5 lb. AI/100 gal. H_2O, use 1 gt./6 in. mound diameter

PESTICIDE SUMMARY DATA SHEET
A. MOUND DRENCH

Chemical Name:
bendiocarb: 2,2-dimethyl-1,3-benzodioxol-4-ol N-methylcarbamate

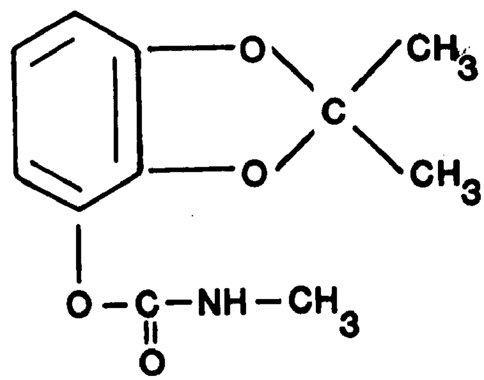
Empirical Formula:
$C_{11}H_{13}NO_4$

Molecular Weight:
NA

Form:
crystalline solid

Odor:
very slight

Chemical Structure:



Trade Names:
Ficam W, BFC Chemicals, Inc.

Chemical and Physical Properties:
m.p.: 128-130 C

v.p.: 5 x 10^{-6} mm Hg at 25 C

solubility:
25 C

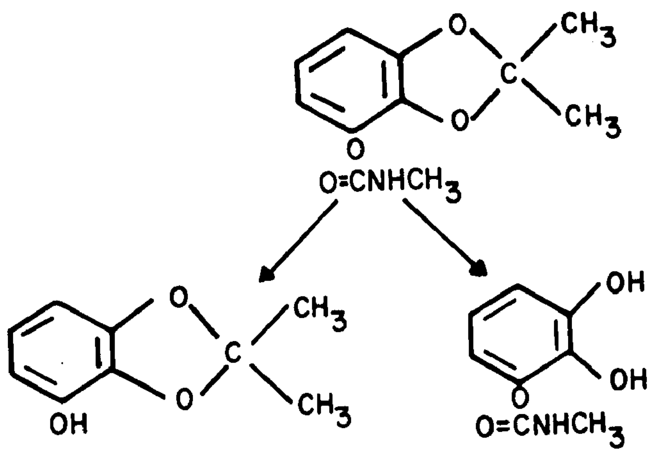
water	0.004%
kerosene	0.03%
trichloroethylene	1.0%
O-xylene	1.0%
chloroform	20.0%
dichloromethane	20.0%
gylcerol formal	30.0%
dimethyl sulfoxide	30.0%

Hydrolysis: 20 C

pH: 5.0 stable
pH: 7.0 t 1/2 10 days
pH: 9.0 t 1.2 150 min

Uses:
1. control of IFA mounds around home (1% dust or 20% WP)
2. perimeter spray to prevent IFA entry into buildings (Ficam 1% dust, WP, 20% WP)
3. IFA mound drench for recreational areas, golf courses, residential areas (by PCO or turf specialist) (Ficam WP)

Degradative Pathways:



Toxicology:
mode of action: direct, rapid reversible inhibitor of acetylcholinesterase

Acute:	LD_{50}
rat, oral	40-156 mg/kg tech.
rat, dermal	566-800 mg/kg tech.
rat, oral	141-250 mg/kg (76% WP)
rat, dermal	1000-2000 mg/kg (76% WP)

Subacute:
rat NOEL (ChE depression) 10 ppm
dog NOEL (ChE depression) 100 ppm

Chronic:
rat NOEL 10 ppm
dog NOEL 20 ppm

Mutagenicity: negative
Teratogenesis: negative (rat, rabbit)
Delayed neurotoxicity: negative (hen)
Reproductive toxicity: negative (rat)

ADI calculated at 0.05 mg/kg/day (LD_{50}):
mallard duck: 3.1 mg/kg
bobwhite quail: 19 mg/kg
chicken: 137 mg/kg

ADI calculated at 0.05 mg/kg/day (LC_{50}):
blue gill: 96 h, 1.65 ppm
rainbow trout: 1.55 ppm
daphnia: 48 h, 31.7 ppm

Formulations:
1% dust, 76% WP, 20% WP

Dosage:
2-3 teaspoonful in 2 gal. water for large mounds

PESTICIDE SUMMARY DATA SHEET
A. MOUND DRENCH

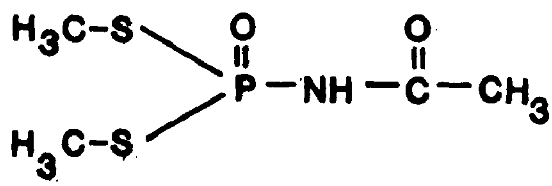
Chemical Name:
Acephate: O,S-dimethyl acetylphosphoramidothioate

Empirical Formula: $C_4H_{10}NO_3PS$

Molecular Weight: 183

Form:
solid

Chemical Structure:



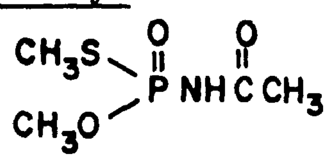
Trade Names:
Orthene, Chevron Chemical Co.

Chemical and Physical Properties:
m.p.: 82-89 C

v.p.: 1.7×10^{-6} mm Hg at 24 C

solubility:
- water: 65%
- acetone: >10%
- alcohol: >10%
- aromatics: <5%

Degradative Pathways:



Toxicology:
mode of action: irreversible inhibitor of acetylcholinesterase

Acute:	LD_{50}
rat, oral	866 mg/kg, 945
mouse, oral	361 mg/kg
rabbit, dermal	>2000 mg/kg
mallard duck	350 mg/kg
pheasant	140 mg/kg
chicken	852 mg/kg

Acute:	LC_{50}
blue gill	96 hr., 2050 ppm
rainbow trout	96 hr., 1000 ppm
channel catfish	96 hr., 2030 ppm
Gambusia	96 hr., 6650 ppm

Uses:

mound drench

Formulations:

75% soluble powder
1.3 lb./gal. soluble concentrate
9.4% soluble powder

Dosage:

2 tablespoonful (1 fl. oz.) in 1 gal. water as mound drench

PESTICIDE SUMMARY DATA SHEET
A. MOUND DRENCH

Chemical Name:
Chlorpyrifos: O,O-diethyl O-(3,5,6-trichloro-2-pyridyl) phosphorothioate

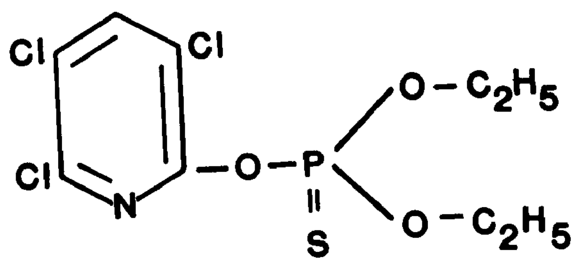
Empirical Formula:
$C_9H_{11}Cl_3NO_3PS$

Molecular Weight:
350.6

Form:
white to tan crystals

Odor:
mild, mercaptan

Chemical Structure:



Trade Names:
Dursban, Dow Chemical

Chemical and Physical Properties:
m.p.: 41.5-43.5 C

v.p.: 1.87×10^{-5} mm Hg at 20 C

solubility:
1.2 ppm

octanol/water partition:
bioconcentration factor 700 (fish)

Degradative Pathways:
(not available)

Toxicology:
Acute:

	LD_{50}
rat, oral	118-245 mg/kg (M)
rat, oral	82-135 mg/kg (F)
mouse, oral	102 mg/kg

Chronic:
rat (2-yr feeding): 0.1 mg/kg/day NOEL

ADI:
0.01 mg/kg/day

reproduction:
rat: NOEL 1.0 mg/kg/day (3rd generation)

teratology:
rat: NOEL 1.0 mg/kg/day

Toxicology: (cont.)

neurotoxicity: no effect in chickens

Uses:

1. individual mound treatment for IFA control
2. ant control in potted and balled nursery stock

Formulations:

Dursban 4E

Dosage:

1 fl. oz./4 gal. water
one gallon applied to mound

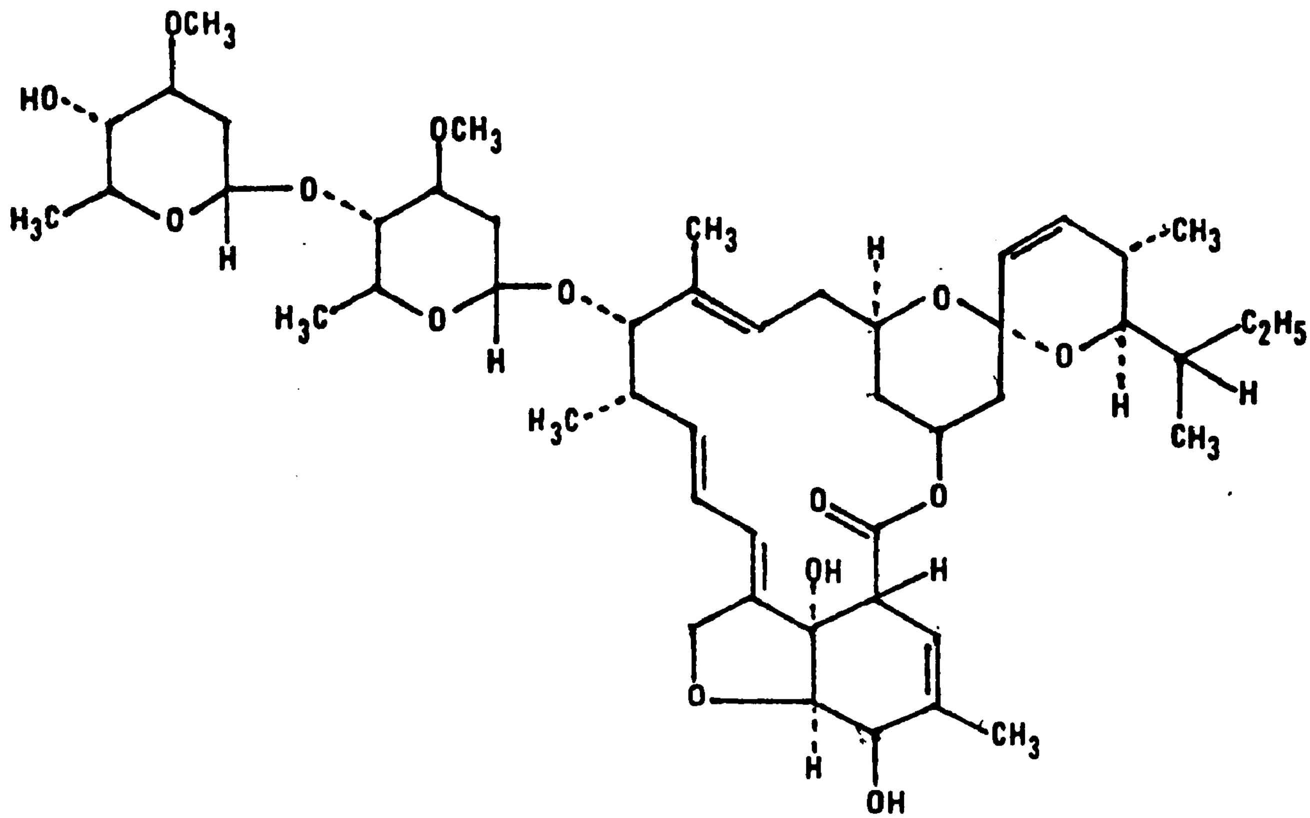
PESTICIDE SUMMARY DATA SHEET
B. BAIT TOXICANT

Chemical Name:
Avermectin B_i

Empirical Formula:
$C_{47}H_{43}O_{14}$

Molecular Weight:
831

Chemical Structure:



Trade Names:
Merck, Sharp & Dohme

Chemical and Physical Properties:
(not available)

Degradative Pathways:
(not available)

Toxicology:
mode of action: gamma-aminobutyric acid antagonist (no effect on cholinergic nervous systems)

Uses:

IFA control (not yet registered)

Dosage:

no label, but 0.0077 g/ha prevented reproductive success in IFA colonies

PESTICIDE SUMMARY DATA SHEET
B. BAIT TOXICANT

Chemical Name:
Ferriamicide (mirex)

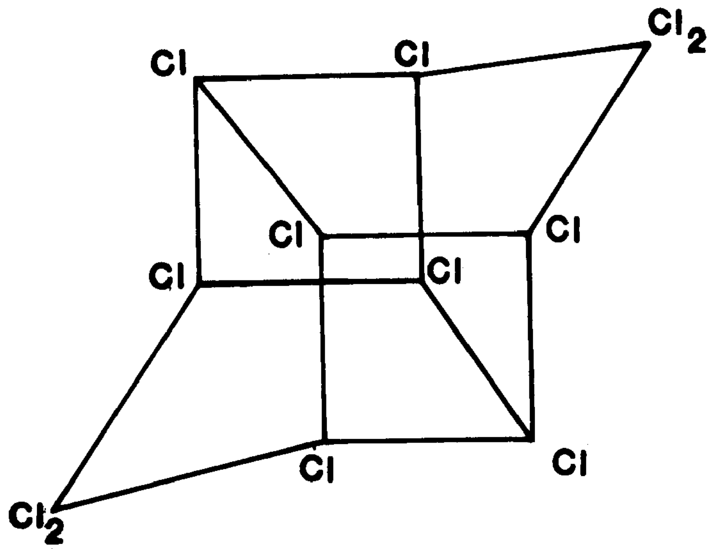
Empirical Formula:
$C_{10}CL_{12}$

Molecular Weight:
542

Form:
white solid

Odor:
odorless

Chemical Structure:

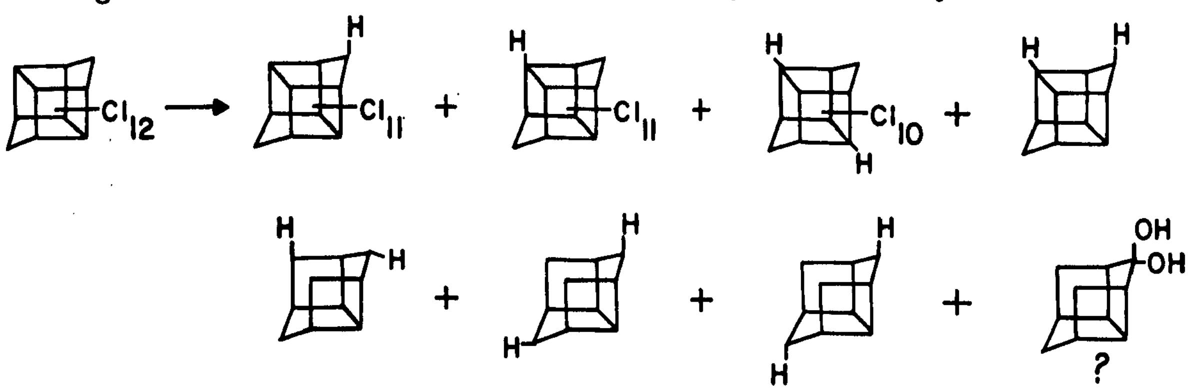


Trade Names:
Ferriamicide

Chemical and Physical Properties:
m.p.: 485 C

solubility:
1 ppg: water
1-30%: organic solvents

Degradative Pathways:
degradable bait: dechlorination photochemically and thermally



Toxicology:

Acute:

	LD_{50}
rat, oral	312 mg/kg
rabbit, dermal	>2000 mg/kg

90-day Subchronic (rat):
- mortality (M): NOEL 320 ppm
- mortality (F): NOEL 80 ppm
- weight: NOEL 80 ppm
- liver wt (M): NOEL 20 ppm
- liver wt (F): NOEL 80 ppm
- histopathology: NOEL 100 ppm

90-day Subchronic (dog):
- mortality (M): NOEL 20 ppm
- mortality (F): NOEL 20 ppm
- liver wt: NOEL 20 ppm
- histopathology: NOEL 100 ppm

teratogenicity:
NOEL 1.5 mg/kg/day

dominant lethal:
negative

acute toxicity:

	LC_{50}
bobwhite quail	2511 ppm
mallard duck	>5000 ppm

	LD_{50}
bluegill	>100 ppm
trout	>100 ppm

Uses:
broadcast or mound application

Formulations:
0.05% mirex; on corn cob grit with amine and ferrous chloride degradation enhancers plus anti-oxidant (citric acid)

Dosage:
1 lb. bait/acre; 0.227 mg AI/acre

PESTICIDE SUMMARY DATA SHEET
B. BAIT TOXICANT

Chemical Name:
N-[1-amino-3-nitro-5-(trifluoromethylphenyl]-2,2,3,3-tetrafluoropropanamide

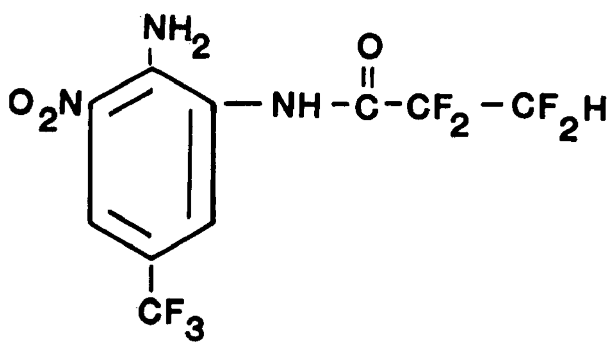
Empirical Formula:
$C_{10}H_6FN_3O_3$

Molecular Weight:
349

Form:
yellow solid

Odor:
Lachrymal

Chemical Structure:



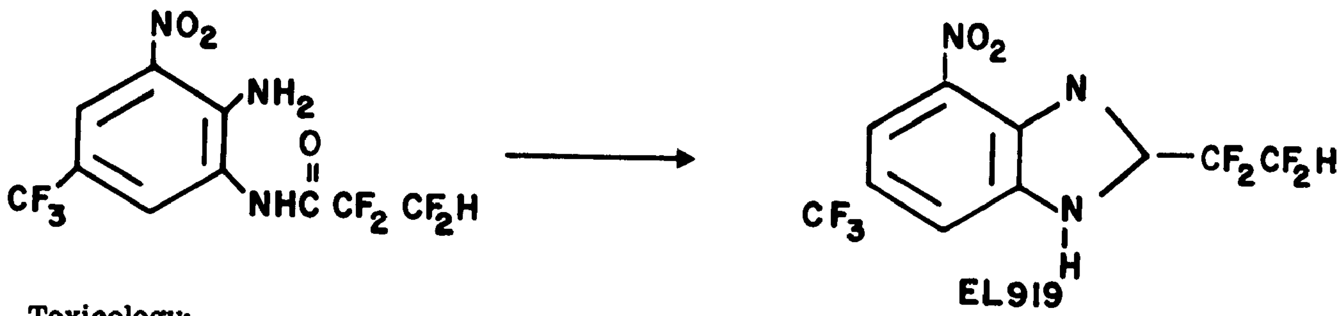
Trade Names:
Bant, EL468, Nifluridide, Eli Lilly, Inc.

Chemical and Physical Properties:
m.p.: 145 C

solubility:
<10 ppm: water
soluble organic solvents
hydrolysis pH:
5 - $T_{1/2}$ = 15.5 hr
7 - $T_{1/2}$ = 3.5 hr
9 - $T_{1/2}$ = 2.0 hr

photolysis (EL919 $T_{1/2}$):
52 days: deionized water
29 days: natural water

Degradative Pathways:



Toxicology:

	EL468	EL919	92452 (NO_2NH_2)
mouse oral (LD_{50})	172	22	253
	-	-	237
mouse S.C. (LD_{50})	57	17	198 (IP)
	54	12	-
rat oral (LD_{50})	48	9	292
	30	7	194
	24	9	176 (IP)
	27	9 (est)	-
dog oral (LD_{50})	24	20	400
rabbit dermal (LD_{50})	500	200	-

Acute toxicity: fish & wildlife:

	EL468	EL919
adult bobwhite (LD_{50})	25.22	4.14
Suv bobwhite, 5-day dietary (LC_{50})	237 ppm	50 ppm
Suv bobwhite, 5-day dietary (NOEL)	90 ppm	-
Suv mallard, 5-day dietary (LC_{50})	50 ppm	16.7 ppm
Daphnia magna, 49 hr static (EC_{50})	516 ppb	678 ppb
Daphnia magna, 49 hr static (NOEL)	300	250
blue gill, 96 hr static (LC_{50})	291 ppb	269 ppb
blue gill, 96 hr static (NOEL)	62	56
rainbow trout, 96 hr static (LC_{50})	708 ppb	528 ppb
rainbow trout, 96 hr static (NOEL)	300	330
earthwork, 14 day (LC_{50})	-	3.68 ppb

Uses:
broadcast bait for IFA control

Formulations:
0.4-0.75% AI
27.6-27.12% vegetable oil
carrier: 72%

Dosage:
2.8 g AI

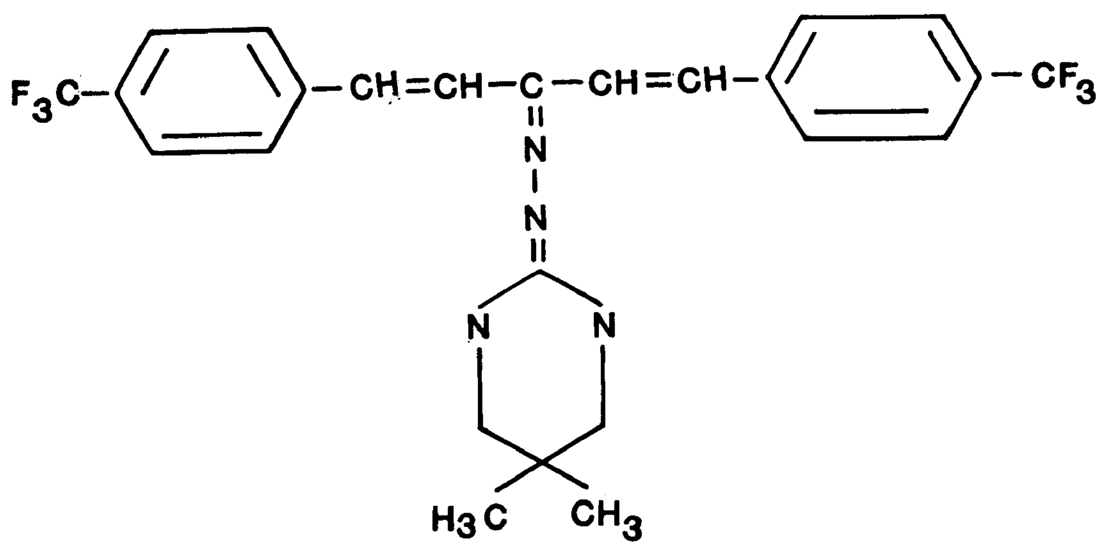
PESTICIDE SUMMARY DATA SHEET
B. BAIT TOXICANT

Chemical Name:
Tetrahydro-5,5-dimethyl-2-(1H)-pyrimidone [3-] [4-trifluoromethyl)-phenyl] -1- [2- [4-(trifluoromethylphenyl)ethenyl] -2-propenylidenehydrazone]

Empirical Formula:
$C_{25}H_{24}F_6N_4$

Molecular Weight:
494

Chemical Structure:



Trade Names:
AC 217,300, Amdro

Chemical and Physical Properties:
solubility:
5-7 ppb

octanol/water partition:
206

Toxicology:
mode of action: stomach poison

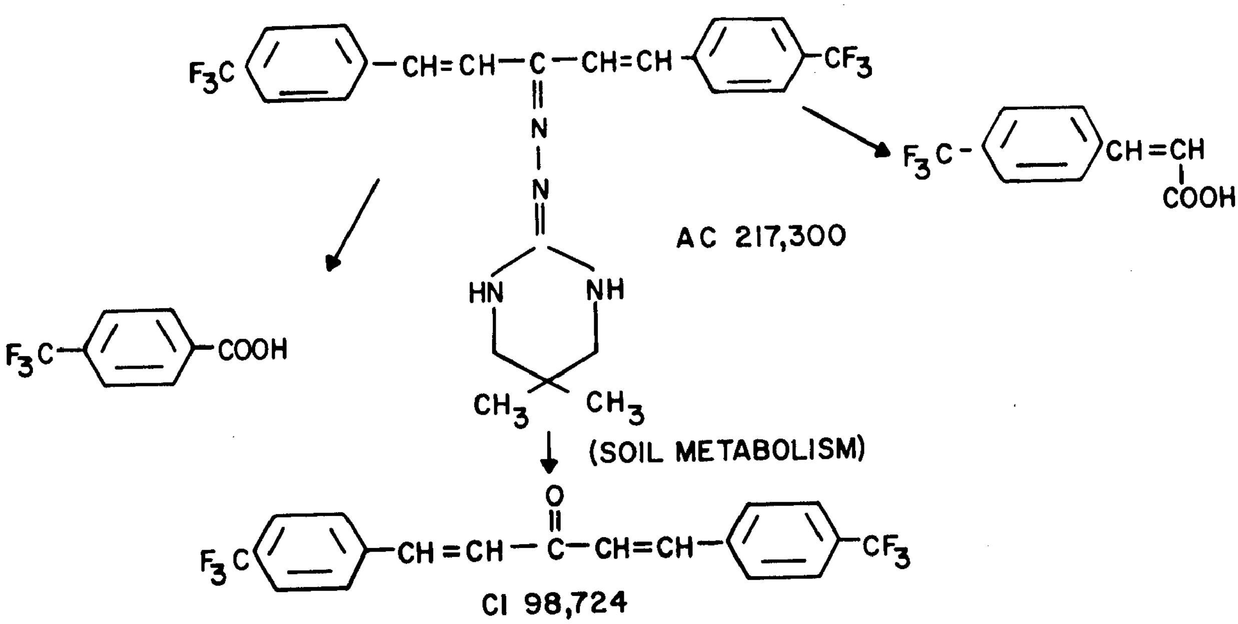
acute:
rat (oral) LD_{50}: 1213 mg/kg
rabbit (dermal) LD_{50}: 5000 mg/kg

subacute:
dog (3-month) (testicular atrophy): 3 mg/kg NOEL
rat (3-month) (testicular atrophy): 50 ppm

reproduction (multigeneration): 50 ppm NOEL (rat)

teratogenicity: negative (rat, rabbit)

Degradative Pathways:



Uses:
conditional registration for IFA control at 4-6 g/acre AI

Formulations:
0.88% bait formulation

Dosage:
4-6 g/acre

PESTICIDE SUMMARY DATA SHEET
C. INSECT GROWTH REGULATORS

Chemical Name:
Methoprene: isoprop 1-(2E,4E)-11-methoxy-3,7,11-trimethyl-2,4-dodecadienoate

Empirical Formula: $C_{19}H_{34}O_3$

Molecular Weight: 310

Form:
amber liquid
Sp. gr 09261 at 20 C

Chemical Structure:

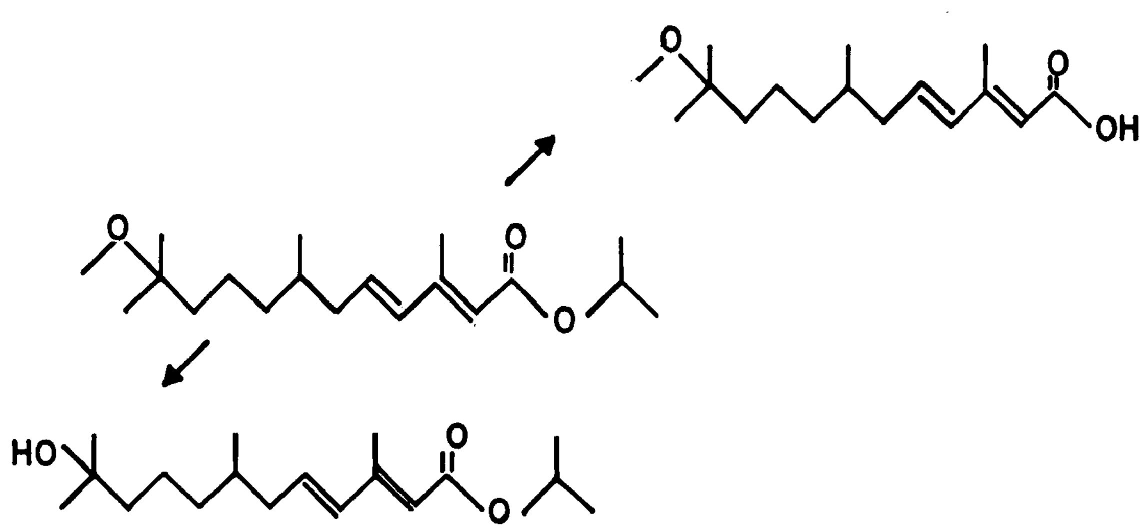
Trade Names:
Altosid, Zoecon Corp., Palo Alto, CA

Chemical and Physical Properties:

v.p.: 2.37 x 10^{-5} mm Hg at 25 C

solubility:
water: 1.39 ppm
soluble in organic solvents

Degradative Pathways:



Toxicology:

acute:

rat (oral) LD_{50}: >34,600 mg/kg
dog (oral) LD_{50}: 5000-10,000 mg/kg

chronic:

neither mortality nor deleterious effects at 5000 ppm in rat and 2,500 ppm in mouse

Uses:

broadcast bait for IFA

Formulations:

1% bait

PESTICIDE SUMMARY DATA SHEET
C. INSECT GROWTH REGULATORS

Chemical Name:
1-(4-isopropylphenyl)-4,8-dimethyl-8-methoxynonane

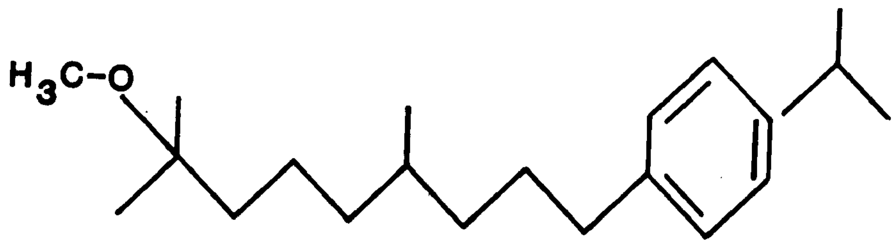
Empirical Formula:
$C_{20}H_{36}O$

Molecular Weight:
NA

Form:
liquid

Odor:
odorless

Chemical Structure:



Trade Names:
MV-678, Stauffer Chemical Co.

Chemical and Physical Properties:
b.p.: 192.6 C/10 mm Hg

v.p.: 9.3 x 10 x 10^{-6} mm Hg at 26 C

solubility:

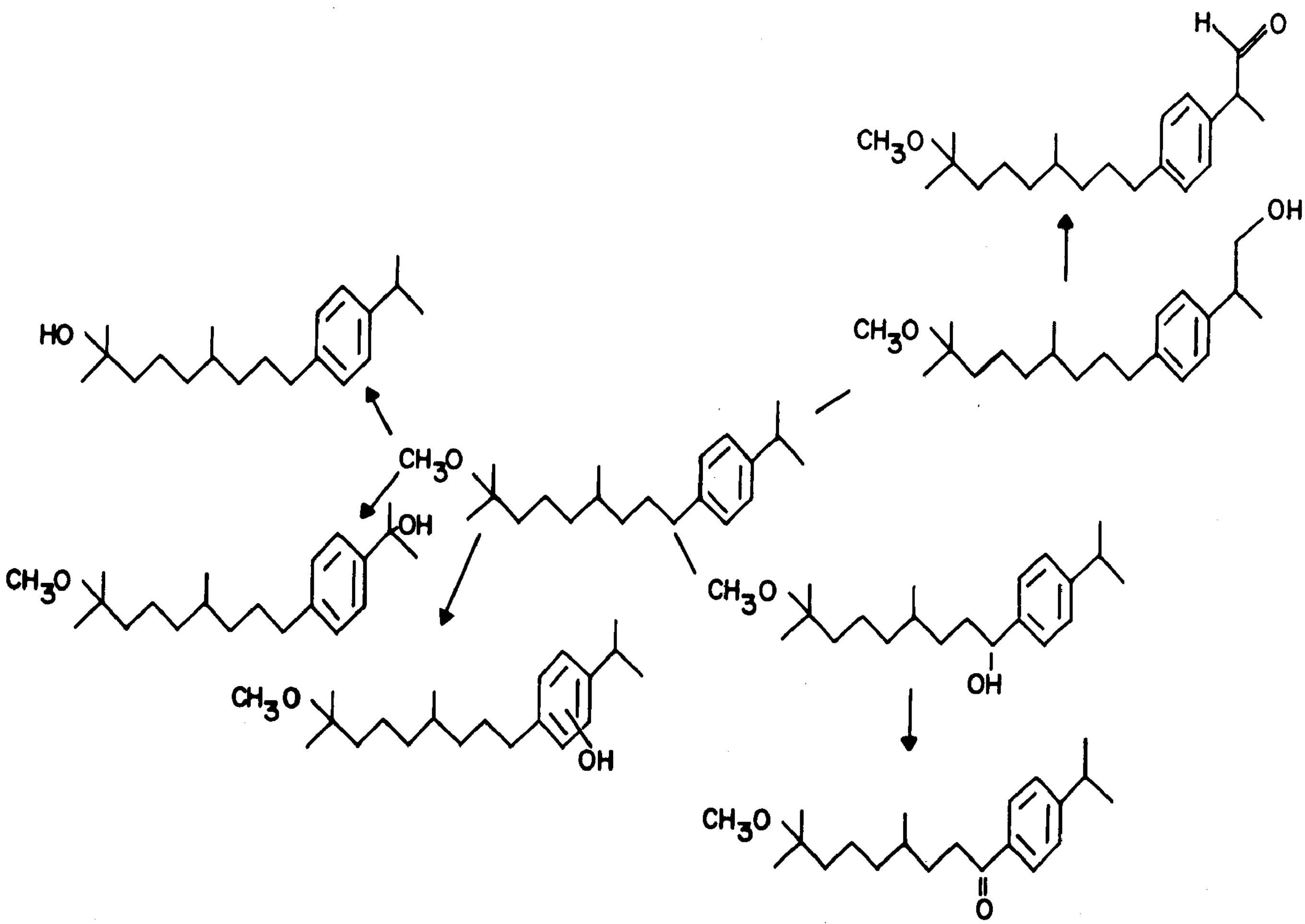
water: 1 ppm 20 C

octanol/water partition:

7.6 x 10^{-4}

hydrolysis:
pH 4.2: 0% 20 days, 6% 31 days
pH 7.0: 0% 20 days, 4% 31 days
pH 9.2: 0% 20 days, 5% 31 days

Degradative Pathways:



Uses:
broadcast bait for IFA

Formulations:
1.2% bait

Dosage:
4.8 g AI/acre, spring and fall

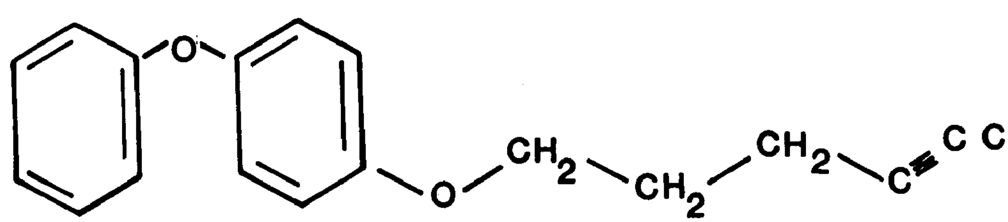
PESTICIDE SUMMARY DATA SHEET
C. INSECT GROWTH REGULATORS

Chemical Name:
1-[(5-chloropent-4-ynyl)-oxy]-4-phenoxybenzene

Empirical Formula:
$C_{17}H_{15}O_2CL$

Molecular Weight:
286.6

Chemical Structure:



Trade Names:
JH-286, Montedison, USA, New York City

Chemical and Physical Properties:
m.p.: 28-30 C

solubility:
soluble in most organic solvents

Degradative Pathways:
(not available)

Toxicology:

acute rat (oral) LD_{50}: >3000 mg/kg

rainbow trout (LC_{50}) 96h: >10 ppm
goldfish (LC_{50}) 96h: >20 ppm
guppy (LC_{50}) 96 h: >10 ppm

mutagenicity: negative

Uses:
broadcast bait for IFA

Formulations:
1% and 2% baits

Dosage:
11-20 g/ha AI

PESTICIDE SUMMARY DATA SHEET
C. INSECT GROWTH REGULATORS

Chemical Name:
ethyl [2-(p-phenoxyphenoxy)-ethyl] carbamate

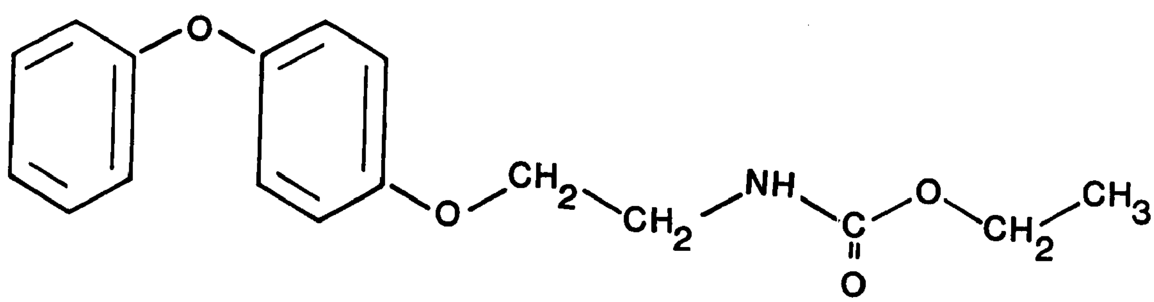
Empirical Formula: $C_{17}H_{19}NO_4$

Molecular Weight: NA

Form: solid

Odor: odorless

Chemical Structure:



Trade Names:
RO 13-5223, MAAG Agrochemicals

Chemical and Physical Properties:
m.p.: 50-53 C

v.p.: 1.3×10^{-7} Torr 25 C

solubility:

water: 6 ppm
acetone: ≥ 24%
diethyl ether: ≥ 26%
dimethylformamide: ≥ 21%
ethyl acetate: ≥ 22%
hexane: 0.8%
isopropanol: ≥ 25%
methanol: ≥ 24%
N-methylpryrolidone: ≥ 20%
toluene: ≥ 23%
hydrolysis: none at pH 4,7,10

Degradative Pathways:

by hydrolysis of OC_2H_5
hydroxylation of phenyl rings

Toxicology:

acute rat (oral) LD_{50}: >16,800 mg/kg
rat dermal (LD_{50}): >2000 mg/kg
mouse oral (LD_{50}): >8000 mg/kg

bluegill (LC_{50}) 96 hr: 2.9 ppm
rainbow trout (LC_{50}) 96 hr: 1.6 ppm
carp (LC_{50}): 10.2 ppm

Uses:
broadcast bait for IFA

Formulations:
1% to 2% bait

Dosage:
6-12 g AI/ha

APPENDIX J

COMMENTS ON FERRIAMICIDE AND THE IFA PROBLEM

Mississippi Department of Agriculture and Commerce

The Mississippi Department of Agriculture and Commerce is fully aware of, and strongly supports, continued research for better, more precisely targeted control methods for the IFA. The Mississippi Department of Agriculture and Commerce has spent in excess of two million dollars for research over the last five years. Meanwhile, in the absence of cost effective control, the IFA population increase has become critical in Mississippi and other infested states.

Today in Mississippi there is an urgent need for a safe, economical, effective method to control this pest. There are on file at the Environmental Protection Agency, in excess of 10,000 letters from individuals, state officials, business firms, and others explaining the damage caused by the IFA and the need for an effective, economical control. Calls are received daily demanding and pleading for assistance in controlling this noxious, destructive pest. Mounds in hay fields have caused farmers to purchase bigger and more expensive equipment to cope with this problem during harvest. It has also forced the soybean grower to leave a portion of his crop in the field to avoid expensive equipment repair and down time. A survey of thirty-five soybean growers in Choctaw County, Mississippi, indicates that a loss of one to three bushels per acre is caused by IFA mounds. Today there is nothing to control this pest on agricultural land.

There are major health related problems caused by the IFA. Desensitization of a child or adult after a life-threatening reaction to the IFA is possible, but not practical for those other than high risk, highly sensitized individuals. Also it does not relieve the parent's concern for their child when ants are present. The presence of the ant in large numbers in areas of high human population is leading to increasing numbers of sensitized individuals; the very young and the elderly are particularly vulnerable. The multiple stings delivered by the ants are a serious health problem for these individuals even if they are not sensitized. What will this problem problem be 10 to 50 years from now? Research indicates that individuals could become highly sensitive to the venom after being bitten or stung.

The Mississippi Department of Agriculture and Commerce has applied to the Environmental Protection Agency for conditional use of Ferriamicide. Ferriamicide is a safe, effective, economical bait for control of the IFA. This bait can be formulated and sold to the user for 29 cents per pound in fifty bags FOB plant.

The rate of degradation of Ferriamicide provides adequate time for it to be effective, but the toxicant disappears from the environment 100 times faster than it did in the old formulation.

The significant and cogent facts concerning Ferriamicide are as follows: Ferriamicide that utilizes the proven IFA toxicant mirex. Under conditions of intended use, Ferriamicide is safe, economical, and efficacious. It utilizes 227 mg per acre of toxicant. In addition to the toxicant, carrier, and attractant, Ferriamicide contains a small amount of amine (approx. 1.7%) and metal salt, which enhances the degradation of the toxicant. The half-life of the toxicant in bait, in laboratories, and field studies is about 30 days. To date, studies indicate the Ferriamicide is (1) effective against the IFA, (2) causes the toxicant to degrade rapidly, (3) has less acute toxicity to nontarget organisms after toxicant degradation has occurred, (4) the degradation products of the toxicants are more polar; consequently, less likely to move in the environment and less likely to biomagnify, and (5) there is evidence that some of the degradation products are further metabolized in mammaliam systems.

About 1,000,000 pounds of technical mirex was used in IFA control programs during the late sixties and early seventies. Application rates were typically 1700 mg per acre. These programs were carefully monitored for harmful efects on wildlife and people. None were observed. In contrast, the negative impact of the ants, particularly regarding health and death of human beings, is well documented. With Ferriamicide, we propose a much more limited application of baits containing only 227 mg of toxicant per acre. The maximum rates of utilization of Ferriamicide, based on the history of the control programs, would be about 15,000,000 pounds per year. At this rate, which is probably too high by at least a factor of two, it would take over 130 years to equal previous use, with a formulation that degrades 100 times faster, and with a compound that even at the heavier use patterns did not cause problems in the real world. Most of the hazards associated with mirex are perceived in the artificial environment of laboratory studies. Residues in wildlife and humans have been observed, but no correlation between these residues and any adverse effect has been made. Further level of residues in humans points to a very low exposure from the 1 to 3 million pounds of technical mirex employed in agricultural and industrial applications.

Reports have circulated for years that due to food chain magnification the real fear of using mirex or its by-products will be apparent in 10 to 20 years. Mirex has been used since 1962 on every size block, and was treated from one to three times. USDA kept complete records as to the date treated, the amount of mirex applied per acre, method of application, etc. Research studies on the habitat of the millions of acres treated since the beginning of the control programs should remove any ecological and environmental fears of using mirex or its by-products once and for all.

Because the IFA is a real health and economic problem to humans, animals, and the economy, we request that the Environmental Protection Agency review applications for control of this pest as quickly as possible and give consideration to the low risk involved because of the small quantity employed and low potential exposure. These risks should then be carefully balanced against the considerable benefits that could be achieved.

COMMENTS ON SYMPOSIUM

We would like to make a few points regarding to subjects that were discussed at some length during the symposium.

1. Much effort was expended discussing eradication strategies, heptachlor programs, and other mistakes of the past. It is good to review past errors, but we would hope that it is clearly recognized that these approaches were adjudged faults and discarded many years ago by those managing the IFA
2. We heard many times that the programs of the past failed to contain or eradicate the ant. The programs in later years were not designed to accomplish these goals. Localized control for localized relief was the goal, and this end was effectively achieved. Most insect control programs are temporary. Why should any intelligent person assume that the IFA programs should be other than temporary unless they are proposing eradications?
3. There is no doubt that when IFA reinfest an area where their population has been depleted that initially a large number of small colonies will result. It is also clear that after a few years the population stabilizes very close to pretreatment levels. In the meantime, close to a year of relief has been achieved, and the resurging mounds are smaller which in many cases present less problems. We strongly agree that designing more specifically targeted baits would be a major contribution to effective IFA control.

9/9/82 Revision

APPENDIX K

FIRE ANT FACT SHEET*

PANEL VI

The following is a summary of the products (pesticides) currently registered for IFA control, including approved Experimental Use Permits (EUP's) and pending products presently under review. This fact sheet identifies formulation types, dosage rates, sites of application, application methods, and related points of interest for each of the pesticides listed.

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*Source: Environmental Protection Agency

1. **Chemical: Amdro** PM-15

Company: American Cyanamid
EPA Reg. No's.: 241-260 and 241-261 (0.88% formulation)
Date Registered: 8/20/80 & 8/17/81, respectively

Description of Application

Site: Pasture and range grass, lawns, turf, and non-agricultural lands
Tolerance: 0.05 ppm (pasture, rangeland grass, and grass hay)
Dosage Rate: 6.0 grams a.i. per acre (5 level tablespoons per individual mound)
Method: Bait broadcast (ground or air application) and mound to mound treatment
Retreatment 4 to 5 months after first treatment if necessary
Is use for quarantine program? No
Restriction: No restriction on user group.

Points of Interest

Added control of harvester ants and big-headed ants to existing label.
Increased storage stability of the product up to three months after opening.

2. **Chemical: Baygon** PM-12

Company: Boyle Midway Inc.
Reg. No.: 475-173 (2% formulation)
Date Registered: 6/10/77
Formulation: 2% Containerized Bait

Description of Application

Site: Around the home (lawns, yards, etc.)
Method of Application: Place ant trap near or on mounds
Is use for quarantine program? No

3. **Chemical: Bendiocarb (Ficam W)** PM-12

Company: BFC Chemicals Inc.
Reg. No.: 45639-1 (76% WP formulation)
Date of Application: 3-25-81
Date Registered: 8-11-81
Site: Mound drench
Dosage Rate: 0.4 oz./8 gallons water
Method: Sprinkler can
Is use for quarantine program? No
Restriction: For use by pest control operators only

Company: BFC Chemicals, Inc.
Reg. No.: 45639-3 (1% Dust)
Site: Mound drench
Method: Sprinkler can (slurry treatment)
Is use for quarantine program? No
Restriction: No restriction on user group

4. **Chemical: Carbaryl** PM-12

Company: Union Carbide Corp.
Special Local Need (SLN) No.: SC-780024, SC-780025, SC-780026
Date Issued by State: 8/14/78

Description of Application

Site: Lawns, pasture, forage grass
Tolerance: 100 ppm in or on pasture and forage grass
Dosage Rate: 1.0-1.5 pounds active ingredient (lbs. a.i.) per 100 gallons of water. 1 quart of dilution per 6 inches of mound diameter
Method: Mound drench. Repeat if mound activity resumes
Is use for quarantine program? No

Points of Interest

Not renewed by State after 12-31-78

Company: Amchem Products Inc.
SLN No.: SC-790030 (50% WP Formulation)
Date Issued by State: 8/13/79

Description of Application

Site: Lawns
Dosage Rate: Same as above

5. **Chemical: Chlorpyrifos** PM-12

Company: Chevron Co.
Reg. No.: 239-2423 (Amendment) (5.3% EC formulation)
Date of Application: 3/29/79
Date Registered: 6/24/80

Description of Application

Site: Ant mounds
Dosage Rate: 2.5 ounces product per gallon of water
Method: Sprinkler can treatment
Is use for quarantine program? No

Company: Dow Chemical Co.
Reg. No.: 464-343,464-360 (22.4% and 40.8% EC formulation, respectively)
Date of Application: 11/5/79
Date Registered: 11/17/80

Description of Application

Site: Potting plants
Dosage Rate: 8 ounces product per 100 gallons of water
Method: Dip and drench treatments
Is use for quarantine program? Yes

Points of Interest

USDA has certified effective control with this product

Company: Dow Chemical Co.
Reg. No.: 464-553 (5% granular formulation)
Date Registered: 12/12/79

Description of Application

Site: Potting media, nursery bench
Dosage Rate: 1.0 lb. product per cubic yard of potting soil
Method: Mix into potting media granular 5%
Is use for quarantine program? Yes

Points of Interest

USDA has certified effective control with this product

Company: Best Products, Inc.
Reg. No.: 20954-46 (6.7% EC formulation)
Date Registered: 8/25/78

Description of Application

Site: Fire ant mounds
Dosage Rate: 2 ounces product per gallon of water
Method: Sprinkler can treatment
Is use for quarantine program? No

Company: Dow Chemical Co.
Reg. No's.: 464-343, 464-360 (22.4% and 40.8% EC formulation, respectively)
Date of Application: 1/17/80
Date Registered: 1/22/81
Site: Mound drench
Dosage Rate: 1 fl. oz./2 gallons water
Method: Sprinkler can treatment
Is use for quarantine program? No

Company: Cessco, Inc.
EPA Reg. No.: 6959-67 (1% spray formulation)
Date of Application: 11/12/81
Site: Mounds-homeowner
Method: Pressurized-mound injection tube
Is use for quarantine program? No
Dosage Rate: 1%-dependent upon mound size as to time tube is left in mound
Date Registered: 3/26/82

6. **Chemical: Diazinon** PM-15

Company: Ciba-Geigy Corp. and others
Reg. No.: 100-456 (25% EC formulation)
Date of Application: 10/31/77
Date Registered: 12/18/79

Description of Application

Site: Lawns and recreation areas
Dosage Rate: 0.016 lbs. a.i. per gallon of water; 1 or more gallon per mound
Method: Mound drench
Restriction: Do not apply to feed/food producing areas
Is use for quarantine program? No

Points of Interest

Claim is only for "aids in control of fire ants." Product directed towards homeowner market.

Company: Thompson-Hayward Chemical Co. and others
Reg. No.: 148-1130 (48% EC)
Date Registered: 8/11/81

Description of Application

Same as above

Company: Hi-Yield Chemical Company and others
Reg. no.: 34911-23 Granules (5% and 14%)
Date Registered: 7/2/81

Description of Application

Site: Lawns and recreation areas
Method: Mound application
Dosage Rate: 0.0125 lbs. a.i./mound
Is use for quarantine program? No

Company: Penwalt Corporation
SLN No.: TX-920015 (23% Flowable Micro-encapsulated)
Date Issued by State: 4/2/82

Description of Application

Site: Lawns and other recreational areas
Dosage Rate: 1 fluid ounce/gallon of water
Method: Mound drench (sprinkler can)
Is use for quarantine program? No

7. **Chemical: EL-468 (Bant)** PM-15

Company: Eli Lilly & Company
EUP No.: 1471-EUP-73 (0.75% formulation)
Date Renewed: 4/30/82-4/30/83

Description of Application

Site: Non-cropland (restricted rangeland and pastureland*)
Tolerance: NA
Dosage Rate: 3.5-6.0 gm ai/A
Method: Bait broadcast or split application (ground or air application)
Retreatment 4 to 5 months after first treatment if necessary
Is use for quarantine program? No
Restriction: Maximum 70 lbs. a.i. over 4600 acres in Texas, Georgia, Florida, Alabama, Mississippi, Louisiana, and Arkansas

*Do not allow beef cattle to graze treated fields until disappearance of the bait is assured.
*Do not slaughter cattle for human consumption which have grazed treated fields without direct consultation with Elanco personnel.
*Do not allow dairy cows to graze treated fields.

8. **Chemical: 1-(8-methoxy-4,8-dimethylnonyl)-4(1-methylethyl benzene) (MV-678)-Insect Growth Regulator (IGR)** PM-17

Company: USDA-Stauffer
EUP No.: 42634-EUP-2 (2.4% bait formulation)
Date of Application: 3/2/79
Date EUP Issued: 5/5/79
Date EUP Extended to: 9/30/83

Description of Application

Site: Non-agricultural land
Method: Aerial application
Is use for quarantine program? No
Restriction: No grazing of animals
Dosage Rate: 0.0025 lbs. a.i. per acre or 0.00025 ounces a.i. per mound

Points of Interest

Existing stocks could be used until 9/30/82 under cooperation of USDA, State, and local government officials.

Company: Same as above
EUP No.: 42634-EUP-2
USDA requested an extension and additional use of MV-678 to be used in Brazoria (County) Texas.
Date Extended: 4/1/82 to 9/30/83

9. **Chemical: Methyl Bromide** PM-16

Company: Velsicol Chemical Co.
Reg. No.: 876-257 (99.9% pressurized gas)
Date Issued: 9/17/69

Description of Application

Site: Around home, non-cropland
Dosage Rate: 1 ounce of product per 10 square feet mound area
Method: Soil fumigation
Is use for quarantine program? No

Points of Interest

According to Company this product has not been marketed for IFA control in the last four years.

10. **Chemical: Orthene** PM-16

Company: Chevron Chemical Co.
EPA Reg. No.: 239-2436 (15.6% EC formulation)
Date Issued: 1/21/81

Description of Application

Site: Around the home
Dosage Rate: 1/2 fl. oz./1 gal. H_2O
Method: Apply on mound and treat a four (4) foot diameter circle around the mound with sprinkling can
Treat new mounds as they appear
Is use for quarantine program? No

11. **Chemical: Pyrethrin I & II** PM-17

Company: Cessco, Inc.
Reg. No.: 6959-58
Date of Application: 10/18/79
Date Registered: 7/2/80

Description of Application

Site: Pastures, golf courses, woodlots, building lots, feed lots, buildings, parks, and playgrounds
Dosage Rate: Spray as necessary
Method: (Pressurized spray) spray directly on ants
Is use for quarantine program? No
Restrictions: Not for house-hold use

12. **Chemical: 1,1,1-Trichlorethane** PM-16

Company: Trichem Industries
SLN No.: TX-780053, MS-800055, LA-800026, LA-800022
Date Issued: 12/11/78

Description of Application

Site: Fire ant mounds
Dosage Rate: 2-4 ounce product per mound
Method: Apply to top center of mound
Is use for quarantine program? No

13. **Chemical: MK-936 (Avermectin B_1)** PM-15

Company: Merck, Sharp & Dohme
EUP No: 618-EUP-10 (0.011% and 0.0055% formulations)
Date of Application: 11/25/81
Date Issued: 5/3/82-5/3/83

Description of Application

Site: Non-cropland
Dosage Rate: 25 mg-50 mg a.i. per acre
Method: Broadcast (ground and air)
Is use for quarantine program? No
Restriction: Maximum 63 grams a.i. over 1680 acres in Alabama, Florida, and Georgia
Do not graze treated fields.

14. **Chemical: Imidan N-(mercaptomethyl) phthalimide S-(0,0-dimethyl phoshordithioate)** PM-15

Company: Zoecon Corp.
EPA Reg. No.: 20954-14-(50% WP in premeasured water soluble packets)
Date Registered: 7/8/82

Description of Application

Sites: Residential, institutional, commercial, and recreational areas
Method of Application: Individual mound treatment (drench)
Dosage: 1 packet (3.8 gms a.i./gal. water/mound)
Is use for quarantine program? No
Restrictions: For sale and use only in the state of Texas

15. **Chemical: Rotenone**

Company: Pennick Corp.
EPA Reg. No.: 432-677
Date Registered: 7/20/82

Description of Application

Site: Gardens, lawns, fields, agricultural land, golf courses, recreational areas, camp grounds and other similar areas.
Method: Drenching the ant mound
Is use for quarantine program? No

16. **Chemical: Heptachlor**

Company: Do-It-Yourself-Pest-Control Inc.
EPA Reg. No.: 13283-4 (5% granular formulation)
Date Registered: 10/21/74

Description of Application

Site: Buried telephone cable closures
Method: Place 4 ounces (premeasured packet) into buried telephone cable closure
Is use for quarantine program? No
Restriction: Packaged for the telephone industry

"Pending" Registration Actions and EUP's for Fire Ant Control

*1. **Chemical: Amdro** PM-15

Company: American Cyanamid
EPA Reg. No.: 241-260 (Amendment) (PP-2F2627)
Date of Application: 1/7/82 & 12/1/81

Description of Application

Site: Cropland (including pineapple and sugarcane) for control of IFA, harvester ants, and big-headed ants
Tolerance: 0.05 ppm for all rac's
Dosage Rate: 6.0 gms/ai/acre for imported fire ants and harvester ants; 10.0 gms/ai/acre for big-headed ants
Method: Bait broadcast (ground and/or air) and mound-to-mound treatment
Limitations: All Food Crops: Do not treat within seven days of harvest.
Pineapple: Do not apply more than two broadcast applications per crop during any twelve month period.
Sugarcane: Do not apply more than three broadcast applications per crop.
Is use for quarantine program? No
Status: Company has submitted outstanding long-term chronic studies. Approval of cropland usage depends upon our review and acceptance of these long-term data. Review completion expected by end of June.

2. **Chemical: MV-678 (same as #8 under registered chemical)** PM-17

Company: Stauffer Chemical Co.
EUP File Symbol: 476-EUP-RNR
Date of Application: 1/27/82

Description of Application

Site: Crop or non-cropland
Dosage Rate: 4.8 gm/ai/acre
Method: Aerial application
Tolerance: None proposed
Status: EUP rejected 4/1/82 due to the need for temporary tolerances or exemption from tolerances on rangeland and other crops. Awaiting company response.

Stauffer Chemical also submitted an application for conditional registration of MV-678
EPA File Symbol: 476-EER
Date of Application: 1/8/82

Description of Application

Same as for EUP above.
Tolerance: An exemption from tolerance was proposed

Status: Objection letter issued 4/6/82. "Biorational" status of chemical in question. Additional data would be needed if chemical is not a biorational. Company responded to our letter 6/1/82. Our answer to the biorational classification is under consideration.

3. **Chemical: Disodium Octaborate Tetrahydrate PM-16**

Company: R Value, Inc.
EUP No.: 44313-EUP-R
Date of Application: 9/11/81
Site: Mounds on unspecified sites
Method: Broadcast application and individual mound treatment
Is use for quarantine program? No
Dosage Rate: 4 lbs. a.i./A (broadcast): 1/4 cup product (mound)
Formulation: 5% bait
Status: Objection letter sent 12/18/81; no response received to date; the applicant had previously indicated that he may try 24(c) registration. The application is incomplete; additional information regarding program is needed.

4. **Chemical: Methyl chloroform (1,1,1, Trichloroethane)**

EPA File: 40708-R Southwest Trichem Industries, Houston, TX
Date of Application: 5/17/77
Site: Urban/rural (non-agricultural)
Dosage: 2 ounces/ant hill
Method: Pouring of chemical on top of ant hill
Formulation: 94.5%
Status: Objection letter dated 11/27/78 (additional safety and chemistry data needed). Company indicated on 6/23/82 that they were interested in pursuing registration and would respond to our objection letter.

5. **Chemical: Resmethrin**

Company: Cessco
File Symbol: 6959-AR, 6959-LO
Date of Application: 10/21/79

Description of Application

Sites: Buildings, playground, pastures, parks, feed, and woodlots
Dosage Rate: Spray as necessary
Method: (Pressurized spray) spray directly on ants
Is use for quarantine program? No
Restrictions: Not for household use
Status: Preliminary acceptance letters issued 6/28/82.

6. **Chemical: Lindane** PM-15

Company: Woolfolk Chemical Co., Inc.
EPA File: 769-LGE
Date of Application: 6/9/82

Description of Application

Site: Home lawns, parks, cemetaries, and recreational and commercial turf areas
Dosage Rate: 4 lbs./1000 sq. ft./ 160 lbs./acre (4 lbs. a.i./acre)
Method: Broadcast ground and individual mound treatment
Is use for quarantine program? No
Status: Under review.

7. **Chemical:** Methylenebis (thiocyanate) PM-31

Company: Vineland Chemical Company
EPA Reg. No.: 2853-43
Date of Amendment Application: 11/2/81
Formulation: 10% liquid

Description of Application

Site: Non-agricultural land
Method: Individual mound treatment (drench)
Dosage: 2 oz. product/gal. water/35 sq./ft.
Is use for quarantine program? No
Restrictions: Not for homeowner use as labeled
Status: Additional efficacy data required and additional testing requested of applicant by Fire Ant Laboratory (USDA) Gainesville, Florida.

APPENDIX L

ERADICATION: AN ASSESSMENT OF CONCEPT AND PRACTICE

Edward H. Smith

PANEL V

It is clear that human population growth, dwindling resources, and global inflation will increase the pressure for more effective pest control. In the case of insect control, we will need all the options we can get. Insect resistance to insecticides is a growing problem. Some of the "third generation" insecticides have not fulfilled thier earlier promise, and the gap between concept and practice is still very wide for some promising control technology such as pheromones. In addition, despite a concerted effort to prevent the introduction of new pests, present methods cannot offset the growing global commerce that increases the likelihood of new pest introductions. The timelessness of this assessment is heightened by new technology which opens options that were previously unavailable. This in turn raises new questions regarding the philosophical, social and economic issues involved in the concept of eradication. And within the many facets of the problem lies the question: Does humankind have the power to eradicate pests, and if so, does it have the right to do so?

Eradication, the elimination of a pest from an environment, has great appeal on two counts. The first appeals to humankind's sense of dominion. In the Judo-Christian philosophy, humans proclaimed their dominion over the earth. They were to "be fruitful and multiply, . . . have dominion over . . . every living thing . . ." To kill and eliminate seems to be a deeply rooted impulse, whether dealing with a mosquito taking a blood meal or fire ants established over thousands of square miles.

The second count, a more rational one, is rooted in cost/benefit relationships. The control of annually recurring pests involves endless effort and expense. The futility of the annual ritual of boll weevil control with the full knowledge that one would be no further ahead the next year offends the sensibility of rational people dedicated to education and research. Some of today's leaders in plant protection have vivid childhood memories of long cotton row, sun, rain, weeds, and insect pests which sentenced them to endless toil. Through the drudgery remained the conviction that there had to be a better way. Despite the tremendous gains in the science and practice of plant protection, however, the magnitude of pest losses has not changed greatly over the past eighty years (Metcalf 1980).

All these things considered, it is not surprising that the concept of eradication greatly appeals to the human intellect. Modern agriculture is essentially the management of resources, the establishment of favored plants in ecosystems where they did not occur naturally, like maize in Africa. To remove pest species from vast areas follows as a natural aspiration in the evolution of agriculture.

SEMANTICS

Professional entomologists differ widely on the issue of eradication. One of the contributing factors to the controversy is the difficulty of aggreeing on what is meant by the term "eradication." For the purpose of this discussion, I define eradication as eliminating an existing pest population from a specified area. The term "eradication" has been so misused and has fallen into such disfavor that one wishes it could be discarded in favor of a term devoid of the ambiguity and prejudice of the past. As this semantic option is not readily available, we can at least qualify our use of the term by including a specification of the geographic area involved.

Withoug specifying the area from which the pest population is to be eliminated, discussions are meaningless. As the target area for eradication increases in size, so do the complexities. While no conceptual and philosophical issues arise in undertaking the eradication of a pest from an individual plant, field, or entire county, many complex issues arise if the scope is regional, continental, or global.

The factor of time also deserves consideration. Presumably, eradication, the elimination of a pest population from a specified area, would last indefinitely or until the pst is reintroduced by humans or gains access by its own migration. clearly the spatial and temporal dimensions of eradication require attention.

PROFESSIONAL PHILOSOPHY

The primary reason whyentomologists have not come to consensus on eradication is that they simply have not addressed the issue seriously. A review of literature shows that the issue has been largely ignored. Other factors have contributed to confusion and ambiguity. As already pointed out, there is ambiguity regarding the meaning of the term. Additionally, many entomologists have direct interest in the issue. The chief proponents of eradication have been USDA scientists, and their leader, Dr. E. F. Knipling, acting as scientist/administrator, has played a key role in advancing the concept and programs. (Knipling 1979). Lines became drawn between state and federal workers. Mistakes of logistics and administration became confused with soundness of concept. Politicians, producers, and environmentalists gathered in the drama and added their biases to those of the professionals.

The issue of eradication was featured at the annual meeting of the Entomological Society of America in 1977. The title of the topic was "Eradication of Plant Pests—Pro and Con" (Bull. Entomol. Soc. Amer., 1978, 24(1):35-53). The format was that of debate; however, as noted by one of the speakers (Rabb), this format was not conducive to an objective treatment of the topic. To conclude that two speakers were "for" eradication and two "against" eradication is inaccurate and an oversimplification. The "con" speakers, Newsom and Rabb, deplored the excesses, weak research data base, escalating budgets, and decision making process in some cases. They offered caution but they did not take a stand of unequivocal opposition to area eradication. The "pro" speakers, Eden and Knipling, acknowledged some mistakes of eradication programs, but urged that the potential benefits of the strategy not be overshadowed by failures of the past, especially in light of the advancing technology applicable to eradication programs. It is unfortunate that the areas of agreement and directions for the future were not more effectively identified in the forum.

The goal of global eradication raises serious moral and philosophical questions. While most case histories of eradication involved objectives much more modest than global eradication, the issue of global eradication needs to be addressed by entomologists. The current range of views is well illustrated by the statements of two contemporary leaders. Newsom (1979) states, "I do not consider it to be morally wrong and ecologically disasterous to attempt to eradicate some pest species." By contrast Metcalf says, "I do firmly believe that species should be regarded as sacred and man indeed has no right or reason to destroy them" (as cited in Perkins, 1982, p. 190).

Perkins (1982) has examined the philosophical foundations of entomology as they have influenced the development of the major new pest management concepts: integrated pest management (IPM) and total population management (TPM). He proposes that these paradigms are imbedded in a matrix of ecological theory with the crucial differences being in the position accorded humans. He subsequently applies labels to the underlying presuppositions of IPM and TPM:

"Integrated Pest Management

'Naturalistic'—A belief system that man is a part of the biosphere but that he cannot be the total master of it. He may manipulate for his own benefit, but there are intrinsic limits to his manipulative powers that reside in the properties of the material world."

"Total Pest Management

'Humanistic'—A belief system that man is part of the biospere and that he can be master of it. He may manipulate it for his benefit, and there are no intrinsic limits to his manipulative powers that reside in the properties of the material world. The limits, such as they are, stem from his current ignorance of natural processes."

Ironically, until the late 1960's, no economist devoted serious attention to the problems of the entomology. More ironic is that even more recently have the philosophical foundations of entomology been considered, despite the burning philosophical question of our relationships to the natural world and our right to eradicate living organisms, termed pests, in a purely anthropocentric classification. Perkin's work drawing on the history of science, philosophy, and a scholarly brush with entomology and its leaders, is certain to stimulate consideration by entomologists of animal rights, the issues of eradication, and related issues of the era of environment and ecology.

INTRODUCED SPECIES

From earliest colonial time, normal commerce has resulted in the introduction of exotic insect species. Sailer (1978) reported that of the 700 important arthropod pests in the U.S. (contiguous states), 35% are introduced species and these account for 50% of total insect losses. Although the threat represented by introduced species was recognized early, it was not until 1912 that the Plant Quarantine Act was passed, but only in 1920 was it fully implemented. Despite concerted efforts by regulatory agencies, species continue to gain entrance at an annual rate of approximately nine species per year (Sailer 1978).

Clearly even with the growing effectiveness of quarantine programs, introductions will continue due to the tremendous speed and volume which characterizes modern transportation of goods and people. According to Elton (1958): ". . . we are living in a period of the world's history when the mingling of thousands of kinds of organisms from different parts of the world is setting up terrific dislocations in nature."

Bates has considered the role of people as agents in the spread of organisms (cited in Thomas 1956) and stresses that "the introduction of an organism into a new region . . . purposeful or accidental, is often possible only because the habitat has been greatly altered by other human activity." As we continue to manage natural systems and commute between continents, the introduction of insect species is certain to increase; therefore two possible strategies could be exclusion, followed by eradication, and finally containment through integrated pest management.

THE CONCEPT OF ERADICATION

The species gaining access to a foreign shore is faced with a formidable problem. It must find a niche, compete for it, and contend with the natural enemies. The ecological complexity of the process is revealed in part by the high proportion of failures in attempts at deliberately introducing species for biological control. The ecological principles involved in the interaction are those inherent in the biotic potential of the species versus environmental resistance. The growing body of knowledge of the dynamics and behavior of insect populations should provide a sounder base for decisions on the feasibility of eradication than has been available.

Eradication seeks to dislodge the species from its niche by increasing environmental resistance. Considering the vulnerability of a species in a new habitat and the numerous biotic and abiotic factors that can be manipulated, the concept of eradication is ecologically sound and appealing. However, numerous factors influence its complexity: size of the area infested, length of time the species has had to adapt to its new habitat, similarity of new habitat to the species' natural range, specificity of food requirements, influence of biological control agents on the population dynamics of the species, technology available for structuring a comprehensive control program, availability of funds and personnel, public support, and cooperation. These considerations are complex and we have had limited experience in dealing with them. A systematic approach to evaluating eradication options is urgently needed.

MAJOR ERADICATION EFFORTS

The early, predominantly rural, American society was much concerned over insect pests and took legislative action to address these and related problems as its agriculture expanded. The Hatch Act of 1888 established agricultural experiment stations, thus providing an organizational structure for conducting research on agricultural problems. Similar organizational effort occurred at the federal level. Some major insect problems appeared shortly thereafter: gypsy moth in Massachusetts (1889), San Jose scale in California (1893), and boll weevil in Texas (1894). These major introduced pests provided a rigorous test for the political structure, the emerging entomology profession, and the concept of eradication. In all three cases eradication was recognized, by some at least, as the first line of defense.

Numerous other eradication efforts have been attempted since then (Table 1). Brown (1961) analyzed four eradication programs, gypsy moth, imported fire ant, Mediterranean fruit fly, and screwworm. His report is drawn upon for the following brief summaries. His analysis considered personnel staffing of the projects, research data base from which programs were projected, and adaptability of programs as they proceeded. He reported striking differences in the resourcefulness of personnel assigned to the four programs and the kind and amount of information on which control operations were based. As might be expected,the programs also differed widely in effectiveness. Based on this analysis, four recommendations were proposed (the validity of which were borne out by later experience):

1. Adequate research must be the foundation for program development with frequent reevaluation to determine effect and need.
2. Expand funding for USDA research with special emphasis on basic studies.
3. Deemphasize mass broadcast of non—selective insecticides with augmentation by other methods.
4. Establish a permanent interagency office to coordinate control activities and evaluate environmental impact.

The following are summaries of several eradication programs.

Malaria. This program was the first undertaken on a global scale. The success with DDT and other residual sprays in the late 1940's and early 1950's prompted the idea of eradicating malaria, and, in 1955 the World Health Organization adopted a resolution in support of this objective. This action was taken despite early signs of anopheline mosquitoes developing resistance to DDT. Another factor was that financial support would wane as early successes reduced the urgency for control. Favorable progress was made until 1966. According to Yekutiel (1981): "The outstanding detrimental factor was inadequate planning and financing . . ."

Additional factors were the increasing problem of insecticide resistance, unforeseen behavioral characteristics of vectors, and factors of human ecology. In retrospect, the malaria eradication program failed to meet a number of prerequisites and now seems unduly ambitious in scope and objective.

Smallpox. In 1959 the World Health Organization passed a resolution to globally eradicate smallpox chiefly by intensive vaccination campaigns. Little progress was made in the following seven years. In 1966 an intensive program was undertaken aimed at eradication within ten years. The objective was reached in 1977 by a campaign involving 46 countries on three continents.

In Dec. 1979 a commission reviewed the evidence and certified the global eradication of the disease (Yekutiel 1981). The presumed eradication of this disease in which vaccination played an important part bears limited analogy to global insect eradication.

Screwworm. The screwworm program represents success and failure of the male sterilization technique. The program was conducted in 1958-59 in southeastern U.S., principally Florida, and involved the release of laboratory-reared, sterilized males from light planes at the rate of 40 million per week. Results were immediate and dramatic. The screwworm was eradicated from the southeastern U.S. at a cost of $10 million.

With this success, attention was turned to a more ambitious project; rolling the screwworm back from southwestern U.S. to a defensible line in southern Mexico. While the program failed in its objective of eradication, it did dramatically reduce the screwworm for the period 1962-76 (Newsom 1978). This experience highlights the difficulty in transposing success from an area where the species was recently established (southeast) to a larger area contiguous with overwintering areas (southwest). The experience also indicated how difficult it is to estimate costs of such a project. More recently, the failure of the autocidal method of control has been explained on the basis of genetic diversity between reared and naturally occurring flies resulting in different reproductive strategies (Richardson et al. 1982). While the southwest eradication program failed based on the objective of eliminating the pest from the area, it did provide valuable information on insect nutrition, behavior, and genetics.

Imported Fire Ant. The red imported fire ant, *Solenopsis invicta* Buren, became established in Mobile, Alabama, in 1943 and gradually spread to ten southeastern states. Its status as an economic pest has been debated for years. The original plan projected in 1957 called for eradication by spraying border areas, centers of infestation, and areas from which it was most likely to spread. The insecticides, heptachlor and dieldrin, were first used, then replaced by mirex bait. The debate over environmental effects of mirex was ended by agreement with EPA that mirex would not be used after 1978. All of the insecticides for IFA control were found to adversely effect the environment, especially wildlife. Thus, the eradication effort ended with the banning of mirex and with the goal of eradication further away than ever. The striking features of this case are that eradication programs based entirely on insecticide treatments proceeded with virtually no research data base on either effectiveness against the target species or non-target species.

Boll Weevil. The boll weevil is the kind of "super pest" that evokes thoughts of eradication. The eradication strategy was proposed when the pest made its appearance in Brownville, Texas, in 1894, but no action was taken and the pest migrated to the eastern seaboard by 1922. The boll weevil has been the target of two major eradication programs: (1) the pilot program initiated in Mississippi, Alabama, and Louisiana in 1972, and (2) the boll weevil eradication program initiated in the North Carolina-Virginia area in 1980. The pilot program was to demonstrate the feasibility of an eradication program, and the second program was to apply the technology. The technology in both cases consisted of multiple control measures including the intensive use of insecticides. The results of the pilot program were hotly debated based chiefly on the issue of the source of boll weevil found within the demonstration area (Perkins 1980). Were they migrants or did they arise from infestations within the demonstration area? Two committees charged with evaluating the program concluded that eradication had not been demonstrated (Chiang et al. 1973). The conclusion by the committee appointed by the National Academy of Sciences to evaluate the more extensive eradication program was that the objective of eradication had not been reached. The committee recommended that "the potential for eradication should be periodically reevaluated" and that there should be "an indefinite postponement of the Optimum Pest Management (OPM) Boll Weevil Eradication (BWE) programs. . . ." (National Academy of Sciences 1981). The debate over the issues continues (Wade 1981). The Committee supported the eradication concept as being worthy of reevaluation, but discouraged implementation pending further advances in technology. The committee's view was undoubtedly influenced by the significant advances made in integrated pest management of cotton pests in recent years (Adkisson et al. 1982).

Mediterranean Fruit Fly. There have been two major efforts to eradicate this pest from Florida and the adjoining area. The first in 1929 involved ten million acres representing three-fourths of the bearing citrus land of Florida. The major features of the program included destruction of fruit in the infested area, strict quarantine, and extensive use of bait spray (brown sugar, molasses, and lead arsenate or copper carbonate). In the short span from April 6, 1929, when infested fruits were discovered until July 1930, the fruit fly was eradicated.

The strategy for dealing with the 1959 infestation was considerably altered from that used in 1929. Destruction of fruit was deemphasized in favor of fumigation. The crude bait used earlier was replaced by protein hydrolysate and malathion applied by air. Eight hundred thousand acres were sprayed one or more times. In addition, detection methods were developed using Angelica seed which was later replaced by a synthetic attractant, siglure, containing esters of cyclohexane carboxylic acid. Through these combined efforts, the fly was eradicated in less than two years with no serious effect on wildlife and relatively little imposition on the public. A striking feature of the 1956 experience was the effectiveness with which the research findings, developed by L. F. Steiner at USDA station in Hawaii, were applied to this problem on the continent.

The cases briefly cited in the foregoing represent both successes and failure. From this limited cross section of cases, several conclusions seem evident:

Early Detection. The Mediterranean fruit fly was on two occasions detected early and dealt with effectively. We tend to assume that this is likely to be the case considering our infrastructure of informed growers, extension and industry personnel, and resource specialists in state and federal agencies, but early detection was not the case with the cereal leaf beetle experience. The cereal leaf beetle was identified in 1962, but had apparently been present for some time and had reached sufficient numbers of 1959 to warrant spray treatment on the initiative of farmers. This occurred in Michigan, a state well staffed by plant protection specialists. The development of surveillance programs for new pests which provide effectiveness at reasonable cost poses a severe problem.

Research Base. Control programs must be based on research findings. Research, however, is difficult to provide, especially when a new pest is discovered and the element of urgency is often invoked as justification to proceed without essential information. It is likely that far more is lost by proceeding with weak programs than by delaying until essential data are available.

Budgeting for Eradication Programs. Accurate budgeting is extremely difficult especially for efforts characterized by so many imponderables. This is to be expected and tolerated to a point, but it is important to distinguish between the factor of the unknown and the practice of covering mistakes by increasing the budget. Skill in assessing progress and adjusting budgets is needed together with advances in technology. Above all, science and technology must take precedence over public relations and politics if credibility of the professionals is to be maintained.

Growing Technology and Experience. Chemical control has been the prevailing strategy for the majority of professional entomologists. Such strategies required little imagination and ingenuity, and the legacy of the low ceiling imposed by their use is still with us. Each case history in eradication has added to our knowledge, despite mistakes that cannot be justified, but growing experience and technology offer a brighter outlook for future programs.

PREREQUISITES FOR ERADICATION

Based on experience of the past and current knowledge of population dynamics, it should be possible to determine with better accuracy the probability of success in eradication efforts. A listing of issues that should be considered follows:

1. High socioeconomic importance of the pest. The eradication strategy generally involves a comprehensive research program to develop the needed technology. This phase is followed by a complex phase involving extensive control programs. Such major effort should be reserved for insect pests of high socioeconomic importance.
2. Specific advantages of eradication over suppression. Unless there is a clear advantage to eradication over suppression, undertaking eradication is not justified assuming effective technology and modest costs for suppression programs.
3. Effective monitoring technology. It is essential that effective technology for monitoring pest populations be available. Without such technology it is impossible to determine the area infested by the pest or the results of treatment. Recent advances in pheromone chemistry and technology offer promise here.
4. Effective control technology. In most cases, eradication efforts will involve a combination of measures. The effectiveness of the total effort must be determined with a high degree of certainty before undertaking eradication. This poses special problems because of the difficulty of interpolating from small, preliminary tests to large area tests. The paucity of data on effectiveness of fire ant treatments was a major weakness of early eradication efforts.
5. Environmentally acceptable programs. The impact of control programs on the environment must be assessed as a prerequisite to launching eradication programs. This poses a difficult problem because of the time element involved in making preliminary determinations.
6. Favorable logistical odds. Large-scale application programs must be basically simple or the element of human error is likely to doom the program to failure. the accuracy of aerial application, or the thoroughness of scouting for infested areas are the kind of operations alluded

to here. The likelihood of failure increases as the area increases. Similarly, the longer the pest has been established, the better it adapts to its environment.

7. Adequate funding to sustain programs. In a number of cases, realistic estimates of costs have not been agreed on before programs are initiated. Undertaking programs with open-ended budgets is likely to place the program in jeopardy for lack of funding or loss of credibility due to excessive costs.
8. Adequate administrative resources to sustain programs. A high level of administrative competence is required to insure coordination of the many facets of an eradication program. This essential input is more difficult to provide when programs extend across state and national boundaries.
9. Favorable socioecological conditions. The success of eradication programs may depend on the cooperation and active participation of residents of the area. It is essential that a high level of support is assured and that regulatory authority can be invoked to take required measures.
10. Favorable cost benefit relationships. The great appeal to eradication programs is that through the initial "capital investment" phase the pests will be eliminated, thereby avoiding the recurring costs of control programs. These cost/benefit relationships need to be calculated very realistically to avoid disalusionment.

Prerequisites cannot assure successful eradication programs. An element of risk will always remain. But by analyzing a program against the list of prerequisites can increase a program's success.

CONCLUSION

Controversy has plagued the eradication concept since its inception. It appears that the weaknesses in technology, logistics, and administration inevitably became confused with basic concept. The result has been that a strategy which should have great appeal has been placed in disrepute, and the stigma has become part of the conventional wisdom of entomology. The myth of the unsoundness of eradication is passed on in the classroom. Objective people would not defend glaring mistakes of past eradication programs, neither would they deny that in some situations eradication offers a high probability for large gains and that a rigorous analytical process can be applied in determining which cases offer such promise. Based on experience to date and future outlook, the following conclusions are drawn.

1. The concept of eradicating an insect pest from an extensive geographical area

is sound biologically, socially, and economically.

2. The eradication strategy has been much maligned because of the errors of past programs.
3. Global eradication or extinction of an insect pest species appears to be an unreasonable objective on technical grounds at this point in the state of art and technology.
4. Global eradication poses complex philosophical considerations that should be addressed. Pending better understanding of the implications of extermination, it should not be acceptable on philosophical grounds.
5. The eradication strategy should be accepted as a viable option subject to rigorous assessments to determine its appropriateness in specific cases.
6. To remove the constraints currently imposed on the eradication strategy will require new alliances of biologists, economists, philosophers, and politicians.

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APPENDIX M

BIOLOGICAL CONTROL: ITS HISTORIC USE VS. PROSPECTIVE VALUE TO CONTROL THE IMPORTED FIRE ANT

Frank E. Gilstrap

PANEL V

Biological control of pest organisms is currently receiving a great deal of attention from the public, agriculture, and government. Some of this attention undoubtedly relates to the frequent notion that biological control is simply a matter of getting some "good" organisms and turning them loose to provide control of a "bad" organism. Actually, far more is required for success than simply releasing or protecting "good" organisms. But if success is achieved after the appropriate effort, the payoff is generally well worth the time, energy, and cost. Though originally employed only in entomology to control insects, biological control now includes plant pathology and weed science, the former using microorganisms as antagonists to prevent plant disease, and the latter using insects or plant diseases to control weedy plants. Neither plant science nor plant pathology are germane to the present topic and will not be referred to further.

Most biological control specialists in entomology describe biological control as an ecological process wherein pest individuals are killed by natural enemies and each pest death produces one to many new natural enemies. Biological control occurs only as the result of human activity; when people are not actively involved either by protecting or releasing natural enemies, the same process is called natural control. In practice, biological control is the study and use of natural enemies to regulate pest abundance at levels where they cause no significant detriment to people. Put very simply, biological control is two sets of three items. The first set names the kinds of approaches used, i.e., conservation, augmentation, and importation of natural enemies; the second set names the kinds of organisms used, i.e., parasites, predators, and pathogens.

Conservation is the practice of conserving or protecting natural populations of a known natural enemy, thus encouraging its suppressive action on the pest population. This technique is used for a natural enemy that does not obtain its potential because of some adverse condition or missing environmental requisite (e.g., pesticides, lack or proper habitat, lack of continuity in habitat). The solution is to eliminate the adversity or provide the missing requisite, as is commonly done in insect pest management. Augmentation of natural enemies seeks to enhance the effect of an exotic or indigenous natural enemy by releasing field-collected or laboratory-reared natural enemies in places where they are needed. Both conservation and augmentation assume the use of a relatively effective natural enemy, but one that for some reason cannot achieve its potential. Importation of new exotic natural enemies is the best first option for biological control of an exotic pest. This type of biological control, usually referred to as classical biological control, consists of introducing one to several exotic species of natural enemy for permanent establishment in the area where the exotic pest is causing damage. The term "classical" applies because the historical origins of biological control are tied to numerous successful importation programs of the past.

Importing natural enemies is conceptually based on the fact that often an exotic pest is accidentally established in a new environment without the controlling effects of natural enemies from its native home. Exotic arthropods are only rarely pests in their aboriginal homes, largely because of natural enemies that effectively control it. The biological control program seeks to identify these natural enemies in the pest's area of origin, ascertain their beneficial status, and then import and release them for establishment. This type of biological control has obtained a worldwide total of at least 120 successful programs on 120 different pest insects; 42 of these programs have resulted in complete and permanent control of the subject pest (Coppel and Mertins 1977). Put another way, each of these 42 programs was so successful that the object pest no longer causes any significant loss or damage. The remaining 78 programs have resulted in less than total control, but clearly contributed towards solving the pest problem. Examining the record a little differently, of ca. 2300 species of natural enemies introduced for control of pests in ca. 600 different situations (essentially same pests as before but counting each pest control success separately), 34% of the natural enemies became established causing partial to complete control in 60% of the situations (Hall et al. 1980). In all successful cases of classical biological control, the outcome has proven economical and has invariably been environmentally safe. The President's Science Advisory Committee (1965) reported that biological control returned ca. $30 for each research dollar invested. This compares to a return of ca. $4 and $15 for insecticides and insect resistant plants, respectively. These benefits from successful biological control programs continue to accrue ad infinitum or until disrupted. In terms of economical return and safety, the record of classical biological control successes is the product of routine commitment, proper training, and appropriate caution exercised by importing personnel, and it is the product of properly stringent importation regulations enforced by governmental agencies. Classical biological control has historically not been the first control tactic considered for dealing with long established or even new exotic pest insects. Considering long established pests, 17 of 28 identified major insect and mite pests in the U.S. are exotic in origin (Van den Bosch 1975). Some of the more notorious insects and mites of exotic origin include the codling moth, European corn borer, cotton bollweevil, pink bollworm, gypsy moth, Japanese beetle, imported fire ant, alfalfa weevil, green peach aphid, pea aphid, greenbug, cabbage maggot, and European red mite (Knipling 1979, Van den Bosch 1975). Some have been the object of biological control, but most have not and all continue to cause serious damage.

BIOLOGICAL CONTROL AND INSECT PEST MANAGEMENT

Any given crop typically supports several to many phytophagous arthropods, each of which could cause severe damage if not controlled. Those not under natural control may be further suppressed by use of (1) crop cultivars that are resistant to pest damage (= host plant resistance); (2) crop production practices that avoid or minimize pest damage (= cultural control); (3) release of sterilized pests that mate with naturally-occurring pests causing production of non-viable eggs (= autocidal control); (4) chemicals (hormones) that disrupt a pest's normal internal processes such as growth and development, or chemicals (pheromones) that interfere with normal communication between pest individuals of the same species; (5) pesticides that kill pests (and often non-pests) by ingestion, inhalation, or contact with poisons; and (6) biological control that kills pests using other living organisms. These tactics are used unilaterally or in concert depending on the crop, pest insect complex, and level of understanding for the crop's ecology. Integrated pest management (IPM) occurs when several of these tactics are combined, or when one to several are used based on a well-founded economic threshold, or when the purpose of a control procedure is to optimize yield with costs of production.

Historically, the crisis of insecticide resistance provoked the serious study of biological control as a major component of IPM. Significantly, this push-pull relationship between insecticide resistance and biological control is changing. Current emphasis on biological control is inspired more by economic and environmental protection considerations than as a choice of last resort. Crop production systems that use biological control almost always use other tactics. Thus, the concept of IPM is one whereby one to several tactics are selectively employed in a mutually compatible framework, are based on an economic threshold, and/or are used to optimize yield with costs of production. Biological control is the cornerstone for such IPM programs, whether they be for glasshouse crops, row crops, field crops, or tree crops. In IPM, effective natural enemies are encouraged, protected, or increased for certain pests and other controls are selected for other pests not amenable to biological control. The alternate tools are those least disruptive to important natural enemies needed to control other phytophagous species.

All three biological control tactics are employed in some IPM programs. For example, citrus pest controls in the Fillmore district of Ventura County (California) consist of classical biological control of four once-major pests, augmentative releases for two pests, and occasional pesticides for three pests only partially controlled by natural enemies (DeBach 1974). Other examples of IPM using biological controls as the focus include peaches in California and apples in Washington (Hoyt and Caltagirone 1971), glasshouse crops in Europe (Hussey and Bravenboer 1971, Markkula 1978), citrus in Israel (Harpaz and Rosen 1971), and sorghum pests in Texas (Young and Teetes 1977, Teetes et al. 1973, Starks et al. 1972). In each example, effective natural enemies are either imported and established for essentially permanent control, released periodically when normal natural enemy activity is insufficient for control, or are conserved when non-biological controls are needed for pests not controlled by natural enemies.

The invasion of an introduced pest is potentially the most disruptive event to affect a well-researched IPM program. Introduced pests usually originate in a foreign country and are not yet adequately studied for immediate use of biological controls. Eradication efforts in response to such invasions often result in serious local disruptions to extant biological controls used in IPM, and can hinder progress towards classical biological control of the new pest. Three recent programs are excellent examples of such an effect. The programs are citrus blackfly, *Aleurocanthus woglumi* Ashby, on citrus in Texas (Hart et al. 1978; Hart, personal communication) and Florida (Selhime et al. 1982), and the Comstock mealybug, *Pseudococcus comstocki* Kuwana, on citrus in the San Joaquin Valley of California (Anonymous 1979, Meyerdirk et al. 1981). In each, it was clear from the outset that prospects for complete biological control were excellent, based on previous programs on each pest in other parts of the U.S. or Mexico. Eradication efforts for each pest in each area caused localized outbreaks of other pests previously under control by natural enemies; made pursuit of classical biological control very difficult; and failed in spite of intensive efforts and considerable expenditure of tax dollars. Exotic natural enemies for each pest were eventually established by agencies outside those involved in the eradication effort. The natural enemies brought complete biological control.

The issue is not that eradication was attempted, but that eradication interfered with the pursuit of alternative control efforts long after it was clear that eradication was not possible. Clearly, an ingredient is missing in present protocol for dealing with an introduced pest.

The invasion of the pink bollworm on cotton in the lower deserts of southern California is an exception to the general rule that invading pests are usually poorly researched. This insect had been well researched in Texas where it was suppressed primarily by cultural controls (Noble 1969). However, the key Texas tactics of growing short season cotton varieties and of early crop destruction were not well suited to California conditions. Thus, the pink bollworm became a new key pest and required frequent, large volume insecticide applications. These pesticides totally disrupted the biological controls used in the previous IPM program. Natural enemies suppressing the cotton leaf perforator, bollworm, cabbage looper, salt marsh caterpillar, spider mites, and other pests were killed and these pests resurged to damaging levels. Not only did cotton producers adopt non-selective pesticides and use them heavily, but such use greatly accelerated the development of insecticide resistance in the target pink bollworm and even in other, non-target pests. Thus, a previously well-founded IPM program has become totally useless until the new key pest is controlled in a non-disruptive manner (Emerson 1974, Reynolds et al. 1975). The pink bollworm remains a key pest in spite of considerable research into classical biological control and other tactics, and the normally non-damaging cotton leaf perforator has risen to pest status causing such heavy damage that the future of cotton production in southern California deserts is threatened.

The programs on citrus blackfly, Comstock mealybug, and pink bollworm exemplify what is likely to occur more frequently in the future when an introduced arthropod becomes a serious pest in a new area. The likely, and generally appropriate, response will be an area-wide eradication program, though the issues are occasionally not clear-cut as revealed by Newsom (1978), Rabb (1978), Knipling (1978, 1979), and Eden (1978). However, at the onset of an eradication effort more funds should be devoted to developing alternative controls should eradication fail or falter. This point was made extremely well by W. L. Brown, Jr., who over 20 years ago (Brown 1961) reviewed four area-wide, mass insect control programs, one of which was the imported fire ant. Brown was highly critical of the programs because research was not integrally involved at the onset of each program. In Brown's own words:

> Every mass control campaign should have an adequate research program functioning as far ahead as possible before control operations get under way. The control work should be guided by the research and not the reverse, and every campaign should be re-evaluated frequently to see if a need for it continues.

It seems clear that we have made very little progress towards Brown's suggestion, a fact that is extremely unfortunate as so much progress is needed in view of today's complexities for protection of crops, animal and human health, and the environment.

PROSPECTS FOR BIOLOGICAL CONTROL AGAINST IFA

Though the imported fire ants (IFA), *Solenopsis richteri* Forel and *S. invicta* Buren, have been residents of the U.S. for ca. 64 and 39 years (Hung and Vinson 1978), respectively, biological control of each has progressed only to very early stages. Some natural enemies have been identified in the IFA aboriginal home in South America, but they have not been studied for their roles or ecological impact. This must be done before importations can be seriously considered. Jouvenaz et al. (1981) recently reviewed the current knowledge of biological control prospects for IFA and pointed out that disease, parasites, and predators are scarce and ineffective controls in the U.S.—an expected conclusion given the continual problems by IFA. They also pointed out that preliminary searches for natural enemies of IFA had been done in South America. The tone of their review was that at present, exotic pathogens are almost certainly the only hope for effective biological control of IFA. Such conclusions however, are premature and counterproductive as adequate field evaluations are not yet available for any natural enemy of IFA. According to Jouvenaz et al. (1981) most biological control work has been supported through the USDA-ARS IFA Research Laboratory at Gulfport, Mississippi, and has been done by either personnel at the laboratory or by SAES personnel at the University of Florida or Mississippi State University. If the analysis of the Jouvenaz et al. review is allowed to stand as the operative statement for future biological control work, and if only the extant group working on biological control of IFA continues without addition of others who are trained specifically in the principles of biological control, chances are quite remote for a successful project on biological control of IFA.

The IFA invasion and spread in the U.S. is paralleled in some respects by the invasion of the Argentine ant (described by Elton 1958). The Argentine ant, like the IFA, is an extremely intense and successful competitor. As it invaded new areas, it caused significant reductions in native ant populations. Native ants most affected were those that occupied similar niches. The crux of the Argentine ant story is that when the competitive advantage of Argentine ant was reduced, by chemicals or otherwise, the native ants quickly regained a temporary competitive position. The same kind of phenomenon would probably occur with the IFA in the U.S. if an acceptable non-chemical and economical device is developed or imported to reduce IFA competitiveness. The rationale for area-wide control if IFA could be compared to that needed for biological control of weeds, as biological weed control is also based on reducing the competitive advantage of the exotic weed (Huffaker 1962).

Parasites

Known parasites of IFA are members of either fly family, *Phoridae*, or the wasp family, *Eucharitidae*. Species of *Eucharitidae (Orasema* spp.) have been reported attacking IFA in Uruguay and Brazil (Williams and Whitcomb 1973). The ants apparently are not disturbed by the presence of these parasites during the parasite developmental time within the ant nest. At least 14 species of phorid flies belonging to two genera, *Pseudacteon* and *Apodicrania*, have been reported associated with fire ants in either Brazil or Argentina (Williams and Whitcomb 1973). According to Borgmeier (1963, as cited by Williams and Whitcomb 1973), all species of *Pseudacteon* attack ants belonging to *Solenopsis*, *Lasius*, *Dorymyrmex*, or *Crematogaster*. In nearly all species of phorids attacking ants, the parasites are attracted to disturbed mounds. Generally, only worker caste individuals are parasitized. The larvae, depending on the parasite species, develop in the head capsule of the adult ant (in which case the ant's head falls off at pupation of the parasite) or in the body of the ant larva. In all cases the parasitized individual is killed and a new adult parasite is produced.

According to Jouvenaz et al. (1981) (and those they consulted), none of these parasites offer much potential for suppressing IFA. However, work initiated by Feener (1981) should be studied further before developing any conclusions. Feener's studies strongly suggest that phorids can cause a shift in the competitive balance between ant species. His studies were conducted in Texas, on *Pheidole dentata* and a native fire ant, *Solenopsis texana*, and showed that *Pheidole* was unable to respond naturally in the presence of the phorids. Thus, it did not recruit normal numbers of major worker ants to ward off an invasion by the *Solenopsis*. In the absence of the phorid parasite, *Pheidole* dominated most confrontations with *Solenopsis*, but in the presence of the parsite, the outcome was usually reversed. This reversal of dominance was shown to be seasonal and dependent on the phenology of the parasite. Feener concluded that the

> notorious imported fire ant . . . appears free of phorid parasites in the United States, despite the diverse array of phorid flies (attacking) this species and its close relatives in South America. This freedom may partly explain the high densities of IFA and its competitive dominance over the (indigenous) fire ant in southeastern United States.

Parasites for IFA may be far more important because they disrupt IFA's competitive advantage rather than simply increasing IFA mortality.

Predators

Indigenous predators of IFA have been reported by Bass and Hays (1976), Whitcomb et al. (1973), O'Neal (1974), and Lucas and Brockman (1981). Reports of predators of IFA in South America are essentially only those of Silveira-Guido et al. (1972) which are very general. However, the phenomenon of predation by other species of ants was examined in Florida by Nickerson et al. (1975) who reported that predation could cause up to 60% mortality in post-nuptial IFA queens. Silveira-Guido et al. (1972) in their review of predation in South America, reported on *Solenopsis (= Labauchena) daguerrei* Santschi, a socially "parasitic" ant that takes over nests of IFA in Argentina and Uruguay. When the invader ants are present in the IFA nest, the IFA workers stop tending their own brood and tend those of the invader. Eventually, the IFA colony vigor attenuates and the nest becomes extremely unthrifty. According to Jouvenaz et al. (1981), these ants have little potential for biological control, due either to poor searching ability and/or other factors that inhibit their ability to find colonies of host ants. Additional study is warranted to properly identify causes for low frequencies of occurrence (ca. 4%), and to identify reasons previous investigators were unable to successfully import these parasitic ants to other locations.

Pathogens

Diseases of IFA are reported to occur naturally in the U.S. and in South America (Lofgren et al. 1975). The indigenous pathogens are apparently relatively few and do not seem to exert any significant control in field populations. However, disease is reportedly fairly common in South America where 20 to 25% of the colonies show presence of disease organisms. Jouvenaz et al. (1977, 1980) reported that 22 species in the IFA species complex have been found diseased in either Brazil, Paraguay, Uruguay, or Argentina. Considerable work has been done on microsporidan diseases of IFA in the U.S. (Jouvenaz and Hazard 1978) and in South America (Allen and Silveira-Guido 1974, Knell et al. 1977); however, none have yet been reported as field evaluated either in South America or the U.S.

According to Lofgren et al. (1975), the findings of Allen and Buren (1974), working with a microsporidan disease, is the most promising. Knell et al. (1977) report 50 to 95% of the adult ants in some colonies are infected with the microsporidan pathogen, causing a diseased condition resulting in less vigor and destruction of fat bodies. Jouvenaz et al. (1981) appropriately point out that debilitating diseases might stress fire ant sufficiently to allow other indigenous ants to become more successful in competing with IFA.

RECOMMENDATIONS

1. Studies should be initiated to quantitatively evaluate arthropodial and pathogenic natural enemies of IFA. These studies should consist of life table analyses and/or experimental methods (as outlined by DeBach and Bartlett 1964) and be conducted for two to five years in the IFA aboriginal home.
2. Studies to identify the IFA natural enemy fauna should be continued in the IFA distribution area in South America.
3. A laboratory should be established near the center of origin of IFA in either Argentina or Brazil. This laboratory should be staffed by the minimum number of permanent scientists and be easily accessible to U.S. scientists on temporary duty studying some aspect of IFA.
4. The classical biological control program for IFA should be expanded and should at very minimum include a biological control specialist (with formal academic training in biological control), an insect pathologist, a specialist in taxonomy of parasitic Hymenoptera (Chalcidoidea) or Diptera, a quantitative ecologist, and a taxonomist of Formicidae.
5. Funding should be generated to support field studies of natural enemies of IFA in three or five or more IFA-infested states in the U.S. These studies should be oriented to understanding the ecology of IFA, its competitors, and its natural enemies. Research locations would serve as loci for release of exotic natural enemies when they become available.
6. A review panel should be established,

consisting of an individual from each facet of the total IFA program (regulatory and each research component) and the various parts of the public sector (health, environmental protection, commerce, etc.). This panel's role would be to regularly review progress in the IFA regulatory, control, and research programs and to critique each. A public meeting should follow each such panel meeting.

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APPENDIX N

IMPACT AND MANAGEMENT OF INTRODUCED PESTS IN AGRICULTURE

Marcos Kogan

PANEL V

When insects and plants coexist in evolutionary time, a process of mutual adaptation becomes established. This process known as coevolution results from the accumulation of several lines of defense in the plant and the gradual adaptation of a few herbivorous species to overcome such defenses. In fact some of these defensive traits become positive stimuli capable of eliciting the behavioral responses characteristic of an herbivorous insect's relationship to its host plant. Many of the defensive traits are of a chemical nature and are known as allomones. However, many plant chemicals have an allomonal function against the majority of the herbivores but a kairomonal (or positive) function for a few species (Norris and Kogan 1980). These latter species are the coevolved ones. Key to this adaptive coevolutionary process is the existence of the herbivore and the plant in the same geographic area over an extended period of time.

In addition to the adaptation of the herbivore to the plant, another level of coevolutionary process permits parasitoids and predators of the herbivores to adapt to the habitat provided by the plant with its full complement of defensive morphology and biochemistry. This is the so-called interaction at the third trophic level (Price et al. 1980).

Current coevolutionary theory assumes that plants have evolved to produce an optimal defense strategy against its associated fauna. In turn the herbivores evolved to produce optimal foraging and host selection strategies. The confluence of these optimization processes is a very dynamic system of herbivore/plant interactions. The lines of defense usually presented to the herbivores by the plant include morphological characters such as hairiness, thorns and spines, thickening of epidermal tissues, accumulation of waxy layers, etc. Another line of defense is represented by secondary metabolites. Most of the allomonal and kairomonal compounds mentioned above are secondary metabolites. Under natural conditions the defensive repertoire of a plant operates synergistically with the complement of natural enemies that regulates herbivore populations. Through man's interference in agricultural systems plant natural defenses and natural enemies are often disturbed and the consequences are "ecological explosions" (sensu Elton 1958) of the kind that brought about the present situation with the imported fire ants in the southeastern U.S. (Lofgren et al. 1975).

GEOGRAPHIC ISOLATION OF PESTS AND POTENTIAL HOSTS

When Painter first defined the various categories of resistance in plants against insects in 1951, he established the category of pseudoresistance to encompass those mechanisms that involve the escape of the plant in space or in time from a damaging encounter with a potential pest. This is not, in fact, a true mechanism of resistance. Not all plants are exposed to all potential pests because many simply do not coexist in the same geographic area. As a consequence of the geographic isolation of pests and potential hosts one can identify two factors that often account for the explosive outbreaks that often result from the immigration of a pest into a new region. First the pest may find suitable host plants in the new region. Provided that the feeding niches are not adequately occupied by well adapted native species, the invader will find the plant defenseless. The historical case of the invasion of Europe by the grape *Phylloxera*, *Phylloxera vitifoliae*, illustrates this point. This North American pest species appeared in France in 1861 and rapidly spread to vineyards in other European and Mediterranean countries. By 1880 the French wine industry was on the brink of collapse. Complete control of the pest was achieved after French vineyards were reconstituted using grafts of the susceptible European grape vine scions on the resistant North American rootstocks. The European vine, Vitis vinifera, was extremely susceptible to the *Phylloxera*, whereas the American species of *Vitis*, such as *V. riparia*, *V. rupestris*, and others, are virtually immune to the pest.

The other more commonly reported mechanism is the release of the immigrant pest from the pressure of efficient natural enemies upon invasion of a new area. There are many well documented cases of this phenomenon which remains as the conceptual foundaton of classical biological control.

BREAKING THE GEOGRAPHIC ISOLATION BETWEEN HOST PLANT AND PESTS

The escape mechanisms reported above are obviously disrupted when the geographic isolation between a plant and a potential pest is eliminated. There are two possible ways whereby geographic isolation between hosts and potential pests is overridden. One is the intentional expansion of crops into new areas. The second is the inadvertent introduction or the accidental immigration of a pest into new regions. Most studies on the impact of immigrant pests have used the examples of successful colonization of herbivores in new regions. These can be illustrated by the many cases of immigrant pests. Also, the successful biological control of many weed species illustrates what can be done if the plant is the migrant species and the herbivores are then intentionally introduced to control the host. Less attention, however, has been given to the consequences of introduction of a crop into a new region (i.e., soybeans). In either case, however, the result is an imbalance on the established plant/herbivore system. If the host happens to be a crop plant, the economic impact can be catastrophic.

OVERALL ASSESSMENT OF IMMIGRANT PESTS

Sailer (1978) made an interesting study on the number of immigrant species into the continental U.S. He took into account the total number of species by order including those that were intentionally imported for biological control of insect pests and weeds. According to Sailer, of 1,379 species for which economic importance has been assigned, 236 are in the category of important pests, that is, species that cause economic losses. Of these, some 80 species are expected to be serious pests. According to Glass (1975), of the 35 most important insect pests in the United States, some 20 are of foreign or exotic origin. Among the most important agricultural pests of foreign origin are the European corn borer, the pink bollworm, the boll weevil, the alfalfa weevil, the southern green stink bug, the green bug, and the pea aphid. By comparison with immigrant pests of perennial plants such as forest or orchard trees, range plants, etc. one has the impression that annual agricultural crops are less vulnerable to the ravages of immigrant pests. If one compares the area planted to annual field crops to other crops and to the impact of immigrant pests of these crops around the world this impression may have some foundation. There are some possible natural restrictive barriers for the successful colonization of insects associated with annual field crops. Some of these barriers have been mentioned by Sailer (1978).

1) The absence of adequate host upon arrival of the immigrant: A tropical pest arriving in an area where the host is not grown will have very little chance of survival, for example, pests of soybeans that may be on board airplanes arriving from the Orient and landing in San Francisco (see below).

2) Inhospitable conditions: A similar situation as mentioned above would have happened if the same airplane landed in Chicago in the middle of the winter. The crop would not be present and the climatic conditions would be such that any immigrant pest would have very little chance for survival.

3) Predation by general native predators: The immigrant pest may be welcomed in the new country by a horde of birds and other general predators that usually abound near the possible ports of entry. In this case

the unprotected potential pest would have very little chance for survival.

4) Inbreeding degeneration: Usually, under current quarantine regulations, invaders are those few individuals that manage to escape the controls. These individuals, assuming that they will reproduce, bring a very limited gene pool. The successive generations resulting from these few initial colonizers will be intensely inbred which may have as a consequence an extreme concentration of semi-lethal or lethal alleles that will eventually lead the population to degenerate and dwindle.

With these introductory remarks as a background I would like now to use three examples of introduced pests in their impact on the development of crops and their influence in the ecological research that lead to their control. Then I will discuss the opposite situation, that is, when the plant is the "migrant" and is exposed to a new set of environmental conditions, including a new spectrum of potential pests.

CASE HISTORIES—EXAMPLES OF ACCIDENTAL INVASIONS BY IMMIGRANT PESTS IN AGRICULTURAL CROPS

Among the numerous examples of pests of foreign origin, three illustrate the approaches and the impact that these pests had, not only on the economy of the crops that they attacked, but also on the directions of the research that was stimulated by the very upsurge of these pests. As we will see later, a common consequence of the impact of an immigrant pest is public support to promote allocation of manpower and funds to the problems that they create. These pests are the European corn borer on corn, the cereal leaf beetle on small grains, and the imported crucifer beetle, a very recent invader that causes economic losses to horseradish.

European Corn Borer

This lepidopterous pest of probable European origin was first detected in the U.S. in 1917 in the neighborhood of Boston, Massachusetts. It is, however, probable that the pest had been around since the early 1900s, because after its detection and correct identification, it was recorded over a rather large area, indicating that spread had occurred in previous years. There is excellent documentation about the possible means of invasion. In the early part of the century rather large amounts of broomcorn were imported by New England broom manufacturers. Much of this broomcorn was imported from Hungary and Italy where the crop was known to be commonly infested by the borer. Since the imported broomcorn was often stored for many months prior to processing, the larvae probably completed development within infested broomcorn and the emerging adult moths escaped and proceeded to colonize neighboring corn fields and fields of other host crops.

The European corn borer is a rather polyphagous species capable of developing on a very large number of grasses as well as broadleaf plants. It has some definite preferences for grasses such as barnyard grass, corn, sorghum, and millet, but does well also on many dicot weeds and crop plants. This rather broad host range certainly enhanced the chance for survival of the initial colonizers.

The spread of the European corn borer from the initial focus was rather rapid and continues. According to Brindley et al. (1975), each year the borer spreads into a few more uninfested counties within the states that are known to be infested.

Detailed biological studies started almost immediately with the detection of the pest. Today the European corn borer is perhaps one of the best studied insects. Of great interest to the management of the pest was the early identification of three ecotypes: a northern univoltine, and two multivoltines—central and southern. Table 1 summarizes the chronological expansion of the research activities on various aspects of the biology and control of the European corn borer (based on Chiang 1978).

In summary, after the failure of early attempts at eradication, the current status of the European corn borer in much of the midwestern corn belt is one of a dynamic equilibrium with fluctuating climatic conditions as well as with biological control agents. The European corn borer is still considered one of the key pests of corn in the Midwest, but its impact varies greatly from year to year. There is continuous effort to monitor and to understand the dynamics of these fluctuations and to predict potential outbreaks. Efforts are continuing to identify sources of resistance. Resistant lines to the first brood of the European corn borer have been identified. Research on mechanisms of resistance to the first brood led to the identification of

Table 1. European corn borer research activity in the U.S.

1917, 1st reported by S. C. Vinal near Boston, Massachusetts.

1917-27, Mass. Ag. Exp. Sta. & Bur. of Entomol. (USDA): Surveys, biology, economic impact control methods.

1930-50s, Intensification of research at state exp. stations with geographic expansion of pest, laboratory founded in Ankeny, IA; biology, ecology, biocontrol, host plant resistance, chemical control.

1953-62, Regional cooperative research project on causes of outbreaks: Monitoring regional fluctuations; economic thresholds; effect of parasitoids & diseases; detection of regional biological races.

1963-70, Regional cooperation on detection of biological races.

1973, Regional cooperative project on corn pest management: all phases including modeling and forecasting.

DIMBOA, as a key allomone. This research is classic in the entomological literature. Identifying the resistance source to the second brood has been more evasive. Screening of the germplasm is continuing with more effective methods of mass rearing and artificial infestation. Inbred B52 with high levels of resistance to the second brood has been intensified among some 600 accessions (Brindley et al. 1975). Thus, although, it is a cause of concern for corn growers and researchers, the situation of the European corn borer has stabilized. It is an important economic factor but by no means is it a limiting factor in corn production in the Midwest. Farmers, have learned how to live with the problem and researchers are learning better ways of coping with the problem.

Cereal Leaf Beetle

Haynes and Gage (1981) offer a state of the art review on the cereal leaf beetle situation in North America.

Since the discovery of the cereal leaf beetle, *Oulema melanopus*, in North America in the early 1960s, research associated with this species is a chronology of how society deals with the introduction of an exotic pest. The numerous facets of the programs that were implemented to control cereal leaf beetle reflect the priority placed on structural change in the agricultural production system. The initial response was detection, then eradication and containment, followed by an intensive program of host plant resistance and ultimately a biological control effort of questionable success. A great deal of activity and research effort since the early 1960's added much to the understanding of the cereal leaf beetle problem, but both the activity and the research appear to have had minimal impact on the present or final outcome.

The first official record of cereal leaf beetle occurrence was made in 1962 in Berrien County, Michigan. But, according to Haynes, damaging populations in the area were probably present since the latter part of the 1940's. Thus, actual invasion preceded detection by more than ten years. Expansion of the area infested by the cereal leaf beetle occurred rather rapidly; the current range extends from Illinois in the west to New England states in the east, south into the northern ranges of Tennessee and North Carolina, and north to Wisconsin. Strict quarantine procedures and treatment of potentially infested bales of hay and grain were imposed. Later it was discovered that the cereal leaf beetle overwintered under the bark scale of Christmas trees. Certification for the movement of these trees was required. Eradication efforts covered a period of about seven years and included extensive areas in Michigan, Indiana, and Illinois reaching a peak of over 1.6 million acres blanket-sprayed with carbaryl in 1966. Efforts at eradication were abandoned after the spread of the beetle was out of control and the spray program generated public opposition due to inconvenience to city dwellers (there were lawsuits against the sprays by new car owners for pitted paint on their vehicles).

With the spread of the pest, intensive

programs were initiated in several other areas of research including: sterile male techniques, artificial media for mass production of beetles, attractants, and biological control.

Much of the biological control was based on the idea of mass rearing the parasitoid *Anaphes flavipes* for release. Since the beetles were not easily reared, cultures were maintained on beetles collected in the field. In addition, these stocks of beetles provided materials for an intensive host plant resistance program whereby a large number of wheat, oat and barley lines were screened. As a consequence of this program resistance in wheat was found to be directly related to thrichome length and density. No high levels of resistance were detected in oat and barley lines.

Meanwhile, the biological control program was intensified by importing additional natural enemies of the cereal leaf beetle from Europe. Also an imaginative program was started with the establishment of a parasitoid nursery in the USDA Parasite Laboratory at Niles, Michigan. This nursery concept allowed redistribution of the parasitoids reared on field-infested populations.

The threat of the cereal leaf beetle to small grain production in the Midwest stimulated one of the most concentrated and intensive efforts on researching the life history and ecology of an insect pest. Perhaps the most beneficial outcome of this activity has been the impetus that it provided to the modeling effort at Michigan State University. As a result of this effort a program of early detection and modeling was initiated and provided a pattern for other such programs in other states. An online system was developed and a network of weather stations specifically aimed at providing current weather information for users of the system was also implemented.

Through continuous monitoring of the cereal leaf beetle, it is apparent that populations have generally declined since 1971. The causes for this decline seem to be the result of a combination of factors such as weather related mortality, mortality due to introduced parasitoids, genetic changes in beetle populations, and changes in overwintering habitat (Haynes and Gage 1981).

As was the case with the European corn borer, the cereal leaf beetle is now a permanent feature of the grain production system in North America. Specialists predict that the beetle will remain a sporadic pest requiring occasional treatments. The program also demonstrates that if infestations are not detected very early, efforts at eradication are usually futile. Also, given the particular pattern of adaptation of the pest to the agro-ecosystem, an equilibrium is sooner or later developed. It behooves researchers to strive in the painstaking task of documenting the mechanisms of adaptation so that a better understanding is gained as to the real status of these pests and a perception is also gained as to policies that should be adopted to cope with future immigrant pests.

Imported Crucifer Weevil

Horseradish is a small but a highly valuable crop in southwestern Illinois. In 1977 a grower detected extensive tunneling of some of his roots. The causal organism was the grub-like larvae of a weevil later identified as the European species *Baris lepidii* (Bouseman et al. 1978). An intensive program started for the study of the biology, damage potential and control of the weevil that became known as the imported crucifer weevil. Because of the small number of growers involved in horseradish production in the area, an almost total survey was accomplished in a short time. The problem was well defined and a program for monitoring the infestation was initiated. Despite the circumscribed area of spread no attempts were made at eradicating the pest, because the pest had already invaded wild and other cultivated crucifer species. Instead, mechanisms were studied to reduce the spread and survival of the pest based on a better understanding of its bionomics. Treatments of sets that are used for the vegetative reproduction of the crop were tested using a range of methods from hot water to immersion in synthetic pyrethroid solutions.

The problem, as it happened with the other pests discussed above, seems to be at this time reduced to only sporadic infestations. Methodologies are being developed to cope with these infestations. The main lesson from this episode was the ability of researchers to join forces with growers and generate financial support from state legislators. This support afforded, in turn, a concerted effort towards the study of the problem. Such cooperation between growers and researchers with official legislative support has resulted in a better definition of the problem and improved methods of control.

EXPANSION OF CROPS INTO NEW AREAS

The other method whereby the geographic barrier between plants and potential pests is broken is the expansion of crops into new regions. A good example is provided by the soybean. Typically a temperate zone plant, soybean has been pushed into production into more and more tropical regions. The soybean in the midwestern U.S. is only sporadically affected by serious insect pest outbreaks. The crop grows vigorously during a rather short (100 to 120 day) growing season; however, when it is planted further south, in northern Florida for example, outbreaks of insect pests, in particular the velvetbean caterpillar, occur almost every year and require one or several spray applications per season. The velvetbean caterpillar breeds throughout the year in southern

Florida and probably in more tropical areas of the Caribbean Islands. They migrate north, reaching northern Florida by the time soybean is growing. Several generations are possible during the growing season. The damage caused by these caterpillars can be extremely severe. Similar outbreaks have been observed when soybean was planted into the subtropical regions of Brazil. Extensive damage is detected by the same velvetbean caterpillar and a complex of other defoliators. It is obvious that the phenology of the pest and the crop have been synchronized to a point that the breaching of a geographic barrier has allowed for a new pest syndrome to develop. It is certainly impossible in this case to recommend withholding the expansion of a crop into a certain region, although there are compelling economic reasons for such an action. However, it may be useful, from the standpoint of a global economic analysis of a crop, to take into account these potential risks as a crop is considered for extensive production in a new area. Quite often such decisions are left in the hands of individuals or groups who have little or no concern or awareness of the potential threats that insect and disease pests may have on the economic production of a crop.

FORECASTING RISKY INTRODUCTIONS

As a native crop of the northeastern provinces of China, soybean has been spreading throughout the world as a major legume crop. Fortunately, up to this point no major introductions of serious oriental pests have been detected in the western hemisphere. Two of these pests are of particular concern: (1) pod borers, especially *Leguminivora glycinivorella*, and (2) the soybean colonizing species of aphids, especially *Aphis glycines*. These pests can be extremely serious and could completely upset the economic production of this crop. We have made special efforts to compile the literature on these pests and to get a first hand perception of their role in soybean production in the orient, particularly in China, Korea, and Japan. Although these efforts cannot guarantee that we will detect any invasions early enough to avoid their propagation, they may allow us to establish beforehand a control strategy to adopt should such immigrations take place.

CONCLUDING REMARKS

The impact of immigrant pests in agriculture in the U.S. has been noticeable. In no event, except for perhaps the spread of the boll weevil and the pink bollworm in cotton, have immigrant pests changed drastically the economic production of agricultural crops. They have generated an enormous body of information and stimulated very productive research, such as the mechanisms of resistance in corn to the European corn borer or the modeling of the population dynamics of the cereal leaf beetle. In most cases also an equilibrium position has been established whereby the invading species has been relegated either to the status of a sporadic or secondary pest, or its control became part of a global pest management program. In general, efforts at eradicating the pest came too late to be of benefit. Usually detection of these immigrant pests occurred ten or more years after the probable date of actual immigration. At that point the pest had already spread beyond a reasonable chance for successful eradication. Thus, for the most part, the recommendation for the control of immigrant pests does not differ from that of our most serious native pests. That is, there is no substitute for thorough, intensive scientific research of the population dynamics of the pest and its life system and the development of a global pest management strategy. It is extremely important in the case of very serious potential pests to gain a better understanding of the potential adaptability of these pests prior to their introduction. It would be important, too, to intensify the efforts towards developing of a methodology for the early detection of these pests.

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APPENDIX O

SOME CONSIDERATIONS FOR THE ERADICATION AND MANAGEMENT OF INTRODUCED INSECT PESTS IN URBAN ENVIRONMENTS

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PANEL V

INTRODUCTION

Plant pests that are exotic to all or parts of the U.S. are continually being intercepted at the many ports of entry around the nation. For example, during the period of 1 October 1978 through 30 September 1979, the Animal and Plant Health Inspection Service of the USDA intercepted 18,644 plant pests; 14,002 were insects (APHIS 1981). The number of interceptions has increased slightly each year, (APHIS 1979, 1980), which can be attributed mainly to large numbers of travelers using the airways to commute between countries (G. Snider, APHIS USDA, pers. comm.). These international movements will always represent a potential for the introduction of pest organisms.

This paper will briefly consider some biological, social, economic, and political consequences associated with the introduction of pests (primarily insects) into urban environments. Although emphasis is placed on the California experience, the general trends probably apply to most urban areas throughout the U.S.

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CALIFORNIA AS A CASE STUDY

During the past century, numerous introductions and establishments of insects and other pests have occurred throughout California. No exact figures have been tabulated for all taxonomic groups; however, some idea of the frequency and characteristics of introductions and establishments can be gained by examining records of selected Homopteran families (Table 1).[1] Compared with other insect groups, the introduction frequencies are high and are due to such factors as: 1) many Homopterans are relatively sessile and remain attached to their host plants during transportation; this feature contrasts with members of other groups that have easily dislodged life stages; 2) because of their small size, life stages of many Homoptera are often difficult to detect; and 3) high volumes of plant materials (nursery stock and personal house/yard plants) are continually moved across state boundaries. When detected early and when infestations are small in size,[2] it has been possible to eradicate some of the introduced homopterans, especially the armored scales. However, a few introductions have disappeared without intervention by humans (see Table 2 for more specific information on the homopterans).

Of great interest and concern is the fact that most introduced homopteran species (85%) were first reported in urban centers (Tables 1 and 2). This is an important pattern that undoubtedly applies to pest species in other toxonomic groups as well. Points of air and sea entry into the U.S. are always located in or near significant population centers. Further, when people move among states they generally do so from one urban center to another. It follows, therefore, that urban centers going to remain the point of first discovery of most exotic pests, some of which have potentially serious consequences to agriculture and forestry. For example, the Mediterranean fruitfly, *Ceratitis capitata* (Wiedemann), appeared in the heavily populated San Francisco Bay Area in 1980. In addition, the gypsy moth, *Lymantria dispar* (L.), although, hardly an exotic pest new to the U.S., was first discovered established in California in San Jose in 1976, and again in 1982 in Santa Barbara—both urban centers (Hoy 1982). To the north, gypsy moth activity is concentrated in the Seattle area of Washington, Salem, and Portland Oregon, and Vancouver, B.C.—all urban regions. Examples of other economically important pests, their first discovery sites, and their subsequent eradications are presented in Table 3. As with the Homoptera, most of these species were first discovered in urban areas.

Past experience with introduced pests indicates that species of agricultural, forest, or public health importance have received top priority for eradication and/or subsequent intensive management efforts (for example, Medfly, Japanese beetle, and gypsy moth). The vigor of these efforts, some of which require considerable expenditures of resources, directly relates to adverse impacts (economic or health) expected in the event of widespread establishment. However, species more appropriately characterized as causing aesthetic or nuisance damage, which is typical of urban pests such as most ant aphid species that pose little immediate economic or health threat (see also NAS 1980, Levenson and Frankie 1981), receive considerably less attention as targets for eradication and/or subsequent management. In addition, many pests that are introduced into urban environments are associated with indoor as well as garden or yard situations--difficult habitats for eradication efforts. Further, if surveys reveal that these aesthetic/nuisance pests range beyond one square mile (see footnote 2), the California Department of Food and Agriculture (CDFA) considers them unlikely candidates for total eradication. Quarantines are, however, imposed to keep these infestations localized. Finally, other constraints may seriously limit the kinds of actions taken against introduced aesthetic/-nuisance pests. It follows, in theory, that we should expect a proportionally greater accumulation of pest species in urban versus agricultural or forest environments, of comparable size. For example, the number of new insect pest species established on the largest and most important agricultural crops in northern California over the past 100 years compared to the number of new established species in the largest cities of the same region, should show the totals to be greater in the urban environment, as a whole. Surveying to test this hypothesis would require considerable effort which was not possible given the short time frame for paper preparation; however, the following case histories exemplify the relative ease by which some pests become established in urban environments.

Iceplant Scales Along California Freeways

From June 1971 to June 1973, two scale species, *Pulvinaria mesembryanthemi* (Vallot) and *P. delottoi* Gill, were found to be established in Napa County (north end of the San Francisco Bay). An initial, unsuccessful, effort was made in 1971 to eradicate *P. mesembryanthemi* from one small suburban locality. During the spring of 1973, this scale was found in three cities in nearby Alameda County. The CDFA concluded that (1) the area infested exceeded 100 acres in three cities in Alameda County; (2) the scale was probably not "a truly destructive pest" (agricultural); and (3) there were several obstacles to eradication, which included the difficulty of dealing with hundreds of private residences. As a result, the CDFA did not implement an eradication program.

By 1974, iceplant scales were detected in three San Francisco Bay Area counties where they were causing extensive iceplant mortality in private and public landscape areas. Thus, this urban "nuisance pest" became a potentially serious economic problem since iceplants are extensively used as landscape ground cover in urban areas and for dune stabilization in coastal areas. Between 1974 and 1976, the California Department of Transportation (CALTRANS), which maintains the largest acreage of iceplant in this state (6,000 acres along freeways), became increasingly alarmed as the potential impact of the scale was realized. In 1976, at the request of CALTRANS, Cooperative Extension conducted a pilot study on the efficacy of chemical control. This study revealed that some compounds would reduce scale populations. However, this finding provided only a partial answer for the management of the pest since much remained to be learned about the scales' biology, behavior, and ecology, and how this information could be related to more effective chemical and other control methods.

CALTRANS and CDFA personnel met with University of California researchers at Berkeley in 1978 and resolved to develop a research program aimed at designing and implementing an integrated management program that would effectively deal with the iceplant scale problem. Two coordinated projects were initiated and funded by CALTRANS: one aimed at discovering and establishing natural enemies and the second aimed at elucidating the scale biology, interactions with host plants, and cultural practices that might lessen scale damage. During this same year, foreign exploration to South Africa, the suspected geographic origin of iceplant scales, was conducted. Seven species of natural enemies (parasites and predators) were discovered and imported to California (U.C. Berkeley) for rearing and later release. Several of the parasitoid species are now known to be established in a variety of the climatic zones where the scales are found. These introductions, in addition to natural enemies already present (six species of parasites and predators), appear to be providing good control of the iceplant scales, which have now spread (primarily by wind) to 17 counties, including areas of the Central Valley and Southern California.

Iceplants were initially chosen as a landscape ground cover in California because of their ability to grow in poor soils, tolerance of high temperatures and salt spray, and low water requirements. Prior to the introduction of the scales, iceplants enjoyed a nearly pest-free existence, and most landscaped areas appeared healthy and vigorous. The plant mortality that did occur was attributed to poor soil and nutrient stress. This suggested that while iceplants appeared to be healthy, they were actually growing under suboptimal conditions (J. MacDonald, personal communication). In the presence of scales, iceplant landscapes were subjected to an additional stress that created widespread plant mortality. While biological contol was effective, considerable time was required to colonize and multiply the natural enemies. This time frame often exceeded the tolerance limits of the plants. Laboratory tests indicated that improving soil conditions through fertilization and watering lessened scale damage and improved iceplant vigor and health. By improving the fertilizer regimes of freeway landscapes, it is now possible to maintain landscape quality where scales are present until the natural enemies can control the pest.

The control approach for the scale is an integrated system emphasizing biological control. Presently, a system is being designed that will transfer these research findings to CALTRANS personnel.

Cockroaches in Urban California

The CDFA has recorded the introduction and establishment of nine cockroach species in urban California environments; all of the following species originated from areas outside North America:

Species	Common name
Blatta latoralis (Walker)	Turkistan cockroach
B. orientalis L.	Oriental cockroach ('black beetle')
Blattella germanica (L.)	German cockroach
B. vaga Hebard	Field cockroach
Periplaneta americana (L.)	American cockroach
P. australasiae (F.)	Australian cockroach
P. brunnea Burmeister	Brown cockroach
P. fuliginosa (Serville)	Smoky-brown cockroach
Supella longipalpa (F.)	Brown-banded cockroach

In general, very little effort has been made to eradicate any of these species.

Two of the most recent California introductions, *Periplaneta fuligionosa* and *Blatta lateralis* exemplify how new roach species may become established in California. *Periplaneta fuligionosa* was first discovered in 1970 at Sutter Creek. Since that time it has spread or has been newly introduced from outside the state to several northern California counties and at least two southern California counties. Despite what may be characterized as spotty initial infestations of this species over a 12-year period, no concerted effort was made to eradicate any of the infestations (Dilly, pers. observ.).

B. lateralis was first discovered in 1978 at the Sharp Army Depot near Stockton. At that time, army entomologists determined that the infestation was well established and widespread (however, it was less than one square mile: K. Hansgen, pers. comm.) at the base and had been there for at least two or more years. The entomologists also concluded that the infestation could not be eradicated. Officials of the state of California (see next paragraph) concurred with this assessment (K. Hansgen), and as a result the army opted to institute a chemical control program to manage the population tat a low level. As of this writing, the roach remains confined to Sharp Army Depot; however, a very real potential still exists for range expansion of *B. lateralis* in California from this one small focus.

In summary, cockroaches are not viewed as agricultural pests and therefore do not receive top priority as candidates for eradication by the CDFA. Responsibility for these pests has been largely assumed by the California Department of Health Sciences; however, due to limited budgets and competing (and more serious) public health pests, cockroaches also seem to receive a relatively low priority by that agency. In effect, cockroaches are treated as pests that cause "only" aesthetic or nuisance damage. One may conclude therefore that a relatively lax attitude towards cockroaches has greatly contributed to their successful establishment and spread in California.[3]

BIOLOGICAL IMPACTS

The urban environment abounds with unexploited resources that include a vast array of native and exotic plant species and various structures that humans erect (see Frankie and Ehler 1978). In addition to physical resources, people may be viewed as a resource since they often play an important role in the ecology of urban pests. For example, in the case of newly introduced pests, people may (1) subsequently spread them to adjacent areas after initial establishment, (2) take direct action against them, or (3) fail to take appropriate action against the pests when they are relatively vulnerable because of socioeconomic and/or political constraints (Frankie and Ehler 1978, Nelson 1978, and Frankie et al. 1982).

New pest species usually arrive without their natural enemies. Although this attribute is recognized for agricultural and forest environments, it has been seldom realized in urban environments. For example, a vast array of natural enemies are associated with the cockroach species in their native habitat (Roth and Willis 1960). However, virtually no effort has been made to seek out these enemies to set up biological control programs in the countries where the cockroach species have been long established. A few examples of classic biocontrol have been attempted against introduced pests in urban areas, primarily plant pests, and these are summarized in a National Academy Report on urban pest management (pp. 148-153, 1980).[4] The potential for classic biological control has been emphasized by in a paper by Olkowski et al. (1978) when they used biological control against herbivores on urban shade trees. Although, theoretical classic biological control offers an attractive means for dealing with some introduced urban pests, success is by no means a certainty (consider the gypsy moth program).

As noted earlier, introductions and establishments of pest organisms in urban California environments have occurred continuously for many years. Overall, these establishments amount to a gradual and predictable rate of species accumulation that could result in devastation of nearby agricultural environments by the pest species. Some introductions will be recognized immediately for their potential (e.g., Medfly and other fruit flies). However, others will not manifest themselves immediately. The following case history exemplifies how a relatively subtle urban introduction could develop into a serious agricultural problem.

Japanese Bayberry Whitefly

The Japanese bayberry whitefly, *Parabemisia myricae* (Kuwana), is found in Taiwan, the Philippine Islands, and the southern islands of Japan. Although the whitefly has been intercepted many times in Hawaii (from the Philippines), no evidence indicates that it has become established there. It was listed as a serious pest of mulberry in areas of Japan in the 1920's and is also a minor pest of citrus. The species, however, is well controlled by natural enemies in Japan and in the Philippines.

The whitefly was collected for the first time in the western hemisphere from a nursery in Santa Ana, Orange County, California. Specimens of the insect were collected from Gardenia on 6 October 1978 by agricultural inspectors during a routine nursery inspection. Independently, Los Angeles agricultural inspectors discovered the same species on Robinson naval orange during a routine inspection of a wholesale nursery in San Gabriel on 12 October 1978. A Los Angeles County entomologist, having been informed of the Orange County find, recognized the whitefly and sent it to Sacramento for confirmation. Subsequent inspection of the San Gabriel nursery resulted in discoveries of this insect on Robinson naval orange, Dancy tangerine, Bearss lime, Marsh grapefruit, Eureka lemon, Washington orange, and dwarf birch.

By 6 November 1978, the bayberry whitefly had been found in two nurseries and their urban environs in Orange County and in two wholesale nurseries and their urban environs in Los Angeles County. The known infested area in Los Angeles covered 35 square miles. Further, the wholesale nurseries were shipping infested nursery stock to other counties in California and to Arizona.

By 11 November delimitation surveys revealed the whitefly's presence in nurseries in El Cajon, Encenitas, and La Jolla in San Diego County; Hesperia in San Bernadino County; Carpinteria in Santa Barbara County; Bakersfield, Delano, and Oakdale in Kern County; Fresno in Fresno County; and Lafayette in Contra Costa County (and two locations in nurseries in Phoenix, Arizona). The infested area in Los Angeles extended some 200 square miles.

On 15 November 1978, a committee met to determine a course of action. The committee felt that further data was needed before a sound decision could be made. They postponed any recommendation for action for 60 days. The likelihood of successful chemical eradication already seemed remote. Based on previous experiences with eradication of the woolley whitefly, *Aleurothrixus floccosus* (Maskell), the committee estimated that the cost of chemical eradication for this new whitefly would amount to about 16.5 million dollars over a six-year period. Further, eradication would require the application of about 17.5 million pounds of insecticide. In view of the expected cost, the already widespread distribution, and the good biological control of the pest in Japan and the Philippines, the CDFA in January decided to take no further chemical control or quarantine action. Rather, a biological control program was suggested as an alternative and was initiated through the University of California.

By 22 November 1978 the pest potential of the species in California was already well recognized. It had been found on 45 plant species including citrus, avocado, and deciduous fruit trees. By late 1979, populations began to increase substantially on many hosts. By June 1980, a large block of commercial lemons in Orange County became so heavily infested that insecticide treatments were required. On lemons the growth patterns of the cultural pruning practices meant that the trees produced new growth almost constantly, an attribute preferred by this whitefly. By early 1981, many lemon groves throughout southern California were heavily infested.

Due to the whitefly's short life cycle in California (21 days under greenhouse conditions) and its ability to reproduce parthenogenetically, the whitefly can develop large populations rapidly and can spread quickly from place to place. The early stages are small and without the noticeable wax adornment typical of other whitefly species. It is therefore difficult to locate in low densities during delimitation surveys.

The Japanese bayberry whitefly story

exemplifies the difficulty of finding, controlling, or eradicating an insect pest in an urban environment. When the initial infestation was discovered, it was too large to eradicate. Biological control was the only logical alternative. Unfortunately, to date biological control has not been very effective in either commercial orchard or urban situations in California. This may be due to rapidly developing and dispersing populations which do not allow natural enemies to keep pace. It may also be due to poor acclimatization by recently introduced natural enemies. Hopefully, biological control will eventually reduce the whitefly populations.

SOCIOECONOMIC AND POLITICAL IMPACTS

Where eradication efforts are mounted against exotic pests, eradication must also be conducted in urban areas. Although the pest in question may be of greater concern to agricultural or forest interests than to urban residents, such eradication efforts must be conducted by the ground rules of the urban, not rural, situation. Even in states whose principal industries are agriculture or forest products, vocal and highly organized efforts to compromise proposed "optimum" eradication programs can be expected from today's more informed and sophisticated urban citizenry.

Recent U.S. events concerning toxic chemicals and human health virtually dictate that decision-makers seriously examine the attitudes of urbanites towards standards of environmental quality as they relate to pest management. Findings from a recent national poll by Louis Harris (as reported in Sierra, Vol. 67(4), 1982) exemplify relevant aspects of these attitudes. For example, an overwhelming majority of people, 83%, "want the Clean Air Act enforced as strictly as it is today or even more so." A majority of 65% to 32% also say they oppose any constraint on human helath standards on grounds of cost! Of considerable significance to the politics of decision-making is the fact that, fully 45% of the voters nationwide say that the way a candidate for Congress voted on clean air would probably or certainly affect their vote for that candidate this fall [1982], even if they agreed with him or her on most other issues. When probed further, Harris found that "33% of the voters this fall are prepared to defeat candidates for Congress who yield on Clean Air." In another national survey on environmental issues, conducted by the Council on Environmental Quality (CEQ 1980), pollsters learned that 46% of the interviewees were greatly worried about "the presence of toxic chemicals such as pesticides or PCB's in the environment" (see also Levenson and Frankie 1981).

When these survey findings are considered in light of other socioeconomic and politiacl patterns (e.g., voting strength is in urban rather than in rural areas, and public involvement in decision-making is increasing), one may expect a wider array of pest management decisions in the future. One of these options, that of no action, will increasingly be given serious consideration. This situation in turn should place much greater pressure on research and extension institutions to provide urbanites with high-quality information on the costs and benefits of eradication and/or management options.

CONCLUDING REMARKS

This treatise is the first step towards understanding the processes that lead to the introduction and establishment of pest organisms in urban environments. Future inquiry into this topic might include such matters as:

1. Elucidating the characteristics of introductions and establishments (e.g., frequency of urban vs. agricultural introductions) of a greater representation of pest organisms in California and other states where accurate records are compiled.
2. Developing generalizations about introductions and establishments based on case history accounts from several states. These case histories should also include the socioeconomic and political circumstances associated with the introductions and establishments.
3. Assessing current nursery practices (including assoicated regulations involving movemnets of plant materials) that may be responsible for some introductions.
4. Surveying attitudes of people who transport plant materials across international and state boundaries. Some effort to survey these attitudes has already been attempted by federal quarantine authorities (G. Snider, pers. comm.).
5. Examining pest faunas on native and exotic plant species in given urban areas. Do natives or exotics, for example, have more pest problems (including plant pathogens)? Further, what are the prospects for using biological control agents against exotics and natives (see Ehler 1982)?

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FOOTNOTES

[1]Based on records of the California Department of Food and Agriculture.

[2]One square mile policy: The State of California administers and operates a pest prevention system mandated by Section 403 of the Food and Agriculture Code. Its major components are: pest exclusion, pest detection, pest eradication, and public information and education. Pest detection involves systematic searches for specific pests outside of a known infested area. The goal is to detect incipient infestations before eradication becomes biologically or economically uinfeasible. In the case of insects, the goal is to detect pests (and take appropriate action) before the infestation exceeds 1 square mile.

[3]Many other pest groups, including potentially serious pests such as termites and wood-infesting beetles from overseas crating material, are similarly characterized and treated in the same manner (D. Dilley and R. Gill, pers. observ.).

[4]Two errors should be noted in the biocontrol narrative of the NAS report. The second complete paragraph on page 15 should begin with: "Fifteen pests were the targets of classical biological control from 1890-1969 (Laing and Hamine 1976)."

The third complete paragraph on page 151 should begin with: "In contrast, 106 agricultural, medical/veterinary, forest, and greenhouse pests were the targets for classical biological control."

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Table 1. Numbers of introduced homopteran species that have established in California environments and their probable sites of introduction (see also Appendix I).

Family	Nos. of species intro.	erad.	estab.[a]	Probable intro. site Urban	Agric.	?
Aleyrodidae	7	0	6	7	0	0
Coccidae	29	4	25	22	4	3
Diaspididae	84	30	51	72	12	0
Pseudococcidae	29	4	23	26	2	1
Totals	149	38	105	127	18	4

[a]Species not accounted for through eradication efforts, apparently died out.

Table 2. Introduced and established species of selected homopteran families; dates of first discovery in California; current status in California.

Taxa	Probable intro. site[a]	First discovery in CA[b]	Current status[c]
Aleyrodidae			
Aleurocybotus occiduus Russell	Comm. turf	pre 1950	MP
Aleurothrixus floccosus (Maskell)	Urb	post 1950	SP
Aleurotuba jelinekii (Frauenfeld)	Urb	post 1950	MP
Aleurotulus nephrolepidis (Quaintance)	Nurs	pre 1950	DO
Dialeurodes citri (Ashmead)	Nurs	pre 1950	MP or CP
Parabemisia myricae (Kuwana)	Nurs	post 1950	SP
Pealius azaleae (Baker & Moles)	Nurs	pre 1950	R
Coccidae			
Ceroplastes ceriferus (Fabricius)	Urb	pre 1950	Erad
C. cirripediformes Comstock	Urb	pre 1950	Yard pest
C. cistudiformis Cockerell	Urb	pre 1950	R
C. floridensis Comstock	Urb	post 1950	Erad
C. sinensis Del Guercio	Urb	pre 1950	Yard pest
Coccus hesperidum Linnaeus	Urb	pre 1950	CP
C. longulus (Douglas)	Urb	pre 1950	R
C. pseudohesperidium (Cockerell)	Urb	pre 1950	Erad
C. pseudomagnoliarum (Kuwana)	Ag-Citrus	pre 1950	Citrus pest
Eucalymnatus tessellatus (Signoret)	Urb	pre 1950	DO
Eulecanium caryae (Fitch)	Ag-fr	pre 1950	R
Parasaissetia nigra (Nietner)	Nurs	pre 1950	R
Parthenolecanium corni (Bouche)	Ag-fr	pre 1900	MP
Parthenolecanium fletcheri (Cockerell)	Nurs	pre 1950	R
P. persicae (Fabricius)	Urb	pre 1950	R
P. Pruinosum (Coquillett)	?	pre 1950	Walnut pest
P. quercifex (Fitch)	Nurs	pre 1950	Oak pest (minor)
Physokermes hemicryphus (Dalman)	Urb	pre 1950	R
Protopulvinaria pyriformis (Cockerell)	Urb	pre 1950	MP
Pulvinaria citricola Kuwana	Urb	pre 1950	Erad
P. delottoi Gill: DeLotto Icepl. scale	Urb	post 1950[d]	MP or CP
P. floccifera (Westwood)	Urb	pre 1950	R
P. hydrangeae Steinweden	Urb	pre 1950	R
P. mesembryanthemi (Vallot):Icepl. scale	Urb	post 1950[d]	CP
P. vitis (Linnaeus)	Ag-fr	pre 1950	R
Saissetia coffeae (Walker)	Urb	pre 1950	MP or CP
S. miranda (Cockerell & Parrott)	?	pre 1950	MP

Table 2. (cont'd)

Taxa	Probable intro. site[a]	First discovery in CA[b]	Current status[c]
S. oleae (Olivier)		pre 1950	SP
Toumeyella liriodendri (Gmelin)	Urb	pre 1950	U Erad
Diaspididae			
Abgrallaspis cyanophylli (Signoret)	Urb	pre 1950	R
A. degeneratus (Leonardi)	Urb	pre 1950	R
Acutaspis albopicta (Cockerell)	Urb	pre 1950	Erad
Andaspis mackieana (McKenzie)	Nurs	pre 1950	Erad
Aonidia lauri (Bouche)	Nurs	pre 1950	Erad
Aonidiella aurantii (Maskell)	Nurs	pre 1900	SP
A. citrina (Coquillett)	Nurs	pre 1950	MP or CP
A. taxus Leonardi	Nurs	pre 1950	Erad
Aspidiotus destructor Signoret	Nurs	pre 1950	Erad
A. nerii Bouche	Nurs	pre 1950	SP
A. spinosus Comstock	Nurs	pre 1950	R
Aulacaspis rosae(Bouche)	Urb	pre 1950	MP or CP
Carulaspis juniperi (Bouche)	Nurs	pre 1950	R
C. minima (Targioni-Tozzetti)	Nurs	pre 1950	MP
Chionaspis americana Johnson	Nurs	pre 1950	R
C. etrusca Leonardi	Nurs	pre 1950	CP
C. furfura (Fitch)	Nurs	pre 1950	Erad
C.gleditsiae Sanders	Nurs	pre 1950	Erad
C. wistariae Cooley	Nurs	pre 1950	R
Chrysomphalus aonidum (Linnaeus)	Nurs	pre 1950	DO
C. bifasciculatus Ferris	Nurs	pre 1950	R
C. dictyospermi (Morgan)	Nurs	pre 1950	DO
Clavaspis disclusa Ferris	Ag	pre 1950	?
C. ulmi (Johnson)	Urb	pre 1950	R
Comstockiella sabalis (Comstock)	Nurs	pre 1950	DO
Diaspidiotus liquidambaris (Kotinsky)	Nurs	pre 1950	MP
Diaspis boisduvalli Signoret	Nurs	pre 1950	SP
D. bromeliae (Kerner)	Nurs	pre 1950	R
D. coccois Lichtenstein	Nurs	pre 1950	R
Dynaspidiotus britannicus (Newstead)	Nurs	pre 1950	?
Epidiaspis leperii (Signoret)	Urb	pre 1950	Walnut pest
Fiorinia fioriniae (Targioni-Tozzetti)	Nurs	pre 1950	R
F. japonica Kuwana	Nurs	pre 1950	Erad
F. pinicola Maskell	Nurs	pre 1950	Erad
F. theae Green	Nurs	pre 1950	Erad
Furchadaspis zamiae (Morgan)	Nurs	pre 1950	MP or CP
Hemiberlesia palmae (Cockerell)	Nurs	pre 1950	Erad

Table 2. (cont'd)

Taxa	Probable intro. site[a]	First discovery in CA[b]	Current status[c]
H. lataniae (Signoret)	Nurs	pre 1950	MP or CP
H. rapax (Comstock)	Nurs	pre 1950	MP or CP
Howardia biclavis (Comstock)	Nurs	pre & post 1950	Erad
Kuwanaspis pseudoleucaspis (Kuwana)	Nurs	pre 1950	R
Lepidosaphes beckii (Newman)	Ag-Citrus	pre 1900	MP
L. camelliae Hoke	Nurs	pre 1950	R
L. chinensis Chamberlin	Nurs	pre 1950	Erad
L. conchiformis (Gmelin)	Ag-Figs	pre 1950	MP
L. destefani Leonardi	Ag-Olives	pre 1900	MP
L. gloverii (Packard)	Ag-Citrus	pre 1950	R
L. machili (maskell)	Nurs	pre 1950	R
L. noxia McKenzie	Nurs	pre 1950	Erad
L. pallida Maskell	Nurs	pre 1950	Erad
L. sciadopitysi McKenzie	Nurs	pre 1950	Erad
L. tokionis (Kuwana)	Nurs	pre 1950	Erad
L. ulmi (Linneaus)	Ag-fr	pre 1900	MP
Leucaspis portaeaureae Ferris	Nurs	pre 1950	R
Lindingaspis rossi (Maskell)	Nurs	pre 1950	MP
Lopholeucaspis cockerelli (de Charmoy)	Nurs	pre 1950	Erad
Melanaspis bromeliae (Leonardi)	Nurs	pre 1950	R
M. obscura (Comstock)	Nurs	pre 1950	R
Neopinnaspis harperi McKenzie	Nurs	pre 1950	R
Nilotaspis halli (Green)	Ag-fr	pre 1950	Erad
Odonaspispenicillata Green	Nurs	pre 1950	MP
O. ruthae Kotinsky	Nurs	pre 1950	MP
Parlatoreopsis chinensis (Marlott)	Nurs	pre 1950	R
Parlatoria blanchardii (Targioni-Tozzetti)	Ag-Dates	pre 1950	Erad
P. camelliae Comstock	Nurs	pre 1950	R
P. crotonis Douglas	Nurs	pre 1950	Erad
P. oleae (Colvee)	Nurs	pre 1950	MP
P. pergandii Comstock	Ag-Citrus	pre & post 1950	Erad
P. pittospori Maskell	Nurs	pre & post 1950	R
P. proteus (Curtis)	Nurs	pre & post 1950	Erad
P. theae Cockerell	Nurs	pre 1950	Erad
Pinnaspis aspidistrae (Signoret)	Nurs	pre 1950	MP
P. buxi (Bouche)	Nurs	pre 1950	Erad
P. strachani (Cooley)	Nurs	pre 1950	Erad
Pseudaulacaspis cockerelli (Cooley)	Nurs	pre & post 1950	Erad

Table 2. (cont'd)

Taxa	Probable intro. site[a]	First discovery in CA[b]	Current status[c]
P. pentagona Targioni-Tozzetti	Ag-fr	pre 1950	Erad
P. parlatorioides (Comstock)	Nurs	pre 1950	Erad
Quadraspidiotus forbesi (Johnson)	Ag-fr	pre 1950	R
Q. juglans-regiae (Comstock)	Ag-fr?	pre 1950	MP or CP
Q. perniciosus (Comstock)	Urb	pre 1950	SP
Selenaspidus albus McKenzie	Nurs	pre 1950	R
S. articulatus (Morgan)	Nurs	pre 1950	Erad
S. rubidus McKenzie	Nurs	pre 1950	R
Unaspis euonymi (Comstock)	Nurs	pre 1950	MP or CP
Pseudococcidae			
Antonina graminis (Maskell)	Nurs	post 1950	DO
A. pretiosa Ferris	Nurs	pre 1950	MP
Brevennia rehi (Lindinger)	?	post 1950	MP or CP
Cataenococcus olivaceus Cockerell	Nurs	post 1950	R
Chorizococcus brevicruris McKenzie	Nurs	post 1950	Erad
C. lounsburyi Brain	Nurs	pre 1950	MP
Crisicoccus azaleae (Tinsley)	Nurs	pre 1900	R
C. pini (Kuwana)	Nurs	pre 1950	MP or CP
Dysmicoccus brevipes (Cockerell)	Nurs	pre 1950	R
D. mckenziei Beardsley	Nurs	post 1950	Erad
Ferrisia virgata (Cockerell)	Nurs	post 1950	MP or CP
Heterococcus nudus (Green)	Ag-Comm. turf?	pre 1950	R
Hypogeococcus spinosus Ferris	Nurs	pre 1950	R
Nipaecoccus aurilanatus (Maskell)	Nurs	pre 1950	MP or CP
N. nipae (Maskell)	Nurs	pre 1950	R
Phenacoccus aceris (Signoret)	Nurs	post 1950	U Erad
P. graminicola Leonardi	Urb-Comm. turf?	pre 1950	MP
Planococcus citri (Risso)	Ag-Citrus	pre 1900	SP
P. kraunhiae (Kuwana)	Nurs	pre 1950	DO
Pseudantonina arundinariae McConnell	Nurs	post 1950	Erad
Pseudoccus calceolariae (Maskell)	Ag	pre 1950	MP
P. comstocki (Kuwana)	Urb	post 1950	CP
P. importatus McKenzie	Nurs	post 1950	Erad
P. longispinus (Targioni-Tozzetti)	Nurs	pre 1950	MP or CP
P. microcirculus McKenzie	Nurs	post 1950	U Erad
Rhizoecus dianthi Green	Nurs	post 1950	MP or CP
R. falcifer Kunckel d'Herculais	Nurs	pre 1950	MP or CP
R. kondonis Kuwana	Nurs	post 1950	SP
Trionymus diminutus (Leonardi)	Nurs	pre 1950	R

[a]Ag = agricultural; Comm. turf = commercial turfgrass; Nursery (Comm. turf & Nursery within or directly adjacent to urban areas).

[b]Renovation and modernization of CA quarantine/detection service occurred ~ 1950.

[c]MP = minor pest; CP = common pest; SP = serious pest; R = rare; DO = died out; Erad = eradicated; U Erad = under eradication.

[d]In 1949 a collection of Pulvinaria sp. was taken from ice plant at the U.C. Botanical Garden, Berekley; it subsequently could not be relocated (between 1949-70). Then, in the early 1970's two scale species, P. delottoi and P. mesembryanthemi, were found on isolated plantings of ice plant in the northern San Francisco Bay Area. Although the 1949 Pulvinaria specimens very closely resembles P. delottoi, it is not considered conspecific at this time.

Table 3. The most economically important insect[a] and mollusc pests that have been eradicated from California; dates and location (County) of first discovery. With the exception of numbers 3, 5, 7 and 9, all species were discovered in urban areas.

	First discovery date	Counties
white garden snail	1929	Orange and Los Angeles
obscure snail	1933	Los Angeles
Mexican bean beetle	1950	Ventura
Mexican fruit fly	1954	San Diego
wheat sawfly	1954	Santa Barbara
melon fly	1956	Los Angeles
Khapra beetle	1960	Fresno, Tulare, San Francisco, Madera, King, Los Angeles, Kern, Imperial, Riverside, and San Bernardino
Japanese beetle	1961	Sacramento
Khapra beetle	1966	Imperial
white garden snail	1970	Los Angeles
Japanese beetle	1973	San Diego
medfly	1975	Los Angeles
gypsy moth	1977	Santa Clara
medfly	1980	Los Angeles
oriental fruit fly	1960	Orange
	1960	Santa Barbara
	1966	Orange
	1967	Orange
	1969	Los Angeles
	1970	Los Angeles
	1970	Orange
	1971	Orange and San Diego
	1972	Santa Barbara and Orange
	1973	Los Angeles
	1974	Los Angeles
	1975	San Diego
	1976	Los Angeles and San Diego
	1977	Orange and Los Angeles
	1980	Orange and San Diego

[a]Hall scale, Nilotaspis halli, which is a serious Homopteran pest (see also Appendix I), was discovered in 1952 in Butte and Yolo Counties (agric. environs). It was subsequently eradicated.

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