Environment significantly affects the dynamics of insect populations through both biotic (living) and abiotic (non-living) factors. Biotic factors are density-dependent which means their impact on the insect population is directly proportional to the density (or size) of that population. Parameters, such as parasitoids, predators, diseases, and availability of food are just a few such density-dependent biotic factors. Abiotic factors are density-independent and are, therefore, not influenced by the size of the population on which these parameters act. These factors include such weather effects as rainfall, temperature, humidity, wind, and light. Of the two factors, biotic and abiotic, that which most influences insect populations is the abiotic. Nothing else (other than the activities of people) has a greater influence on determining where insects live and reproduce.

To survive, insects must respond behaviorally and physiologically to environmental change. These responses are not just on a season to season basis, but also on a day to day, or even minute to minute basis. Although many insect species in temperate regions can cope with the rigors of winter through a physiological process known as diapause (in some ways similar to hibernation), imported fire ants have not adapted nor evolved to cope with low temperatures in such an effective manner. However, these ants do exhibit a variety of behavioral and physiological modifications which allows them to survive in otherwise marginal areas. Because of the effect of weather and because of the response of fire ants to the abiotic factors associated with weather, and ultimately climate, the following discussion will focus on the interaction of fire ants with those parameters.

The most obvious factor associated with imported fire ants is the large and durable, conically-shaped dome of soil called the mound. Because fire ants, like all insects, are poikilothermic (coldblooded), their life functions are tied to temperature. As temperature increases and decreases, so does the ants' metabolism. Therefore, the mound is vitally important.

An average mound is approximately 10 inches high and 15 inches in diameter, but older colonies may have mounds as high as two feet and two to three feet in diameter, depending on the soil type. Although the outside surface of the mound often is quite hard and crust-like, the inner area is characterized by a series of interconnecting chambers and tunnels above the soil surface that extends as an inverted cone from one to three feet beneath the ground surface. The mound often is devoid of vegetation and serves as a solar collector during daylight by collecting the sun's energy and storing it as heat. However, this same structure which stores heat by day also serves as a heat radiator at night by giving off heat faster than the surrounding soil. Therefore, a balance is usually met, depending on colony needs between solar gain and solar loss throughout the seasons. The shape and size of the mound also can be changed to accommodate the tempera-
ture needs of the colony. In addition, colonies are known to change location throughout the course of a year because of disturbance or to take advantage of a selected site which may provide more optimal temperature and moisture conditions.

Movement within the mound - Imported fire ants are not able to raise the temperature in the mound by beating their wings or by clumping as do many wasps and bees, but they can modify the temperature in other ways. In addition to a temperature and humidity gradient within the mound, a significant difference exists between temperature regimes in the mound soil and the undisturbed soil adjacent to the mound. Fire ant mounds have been shown to have a higher maximum and a lower minimum temperature during the summer than does the adjacent soil. Also, mounds exhibit a temperature inversion at night in the summer which the ants can exploit.

Temperature and humidity are the most important factors in determining the developmental rate of the young (i.e., eggs, larvae, and pupae). Workers can move the young both vertically and horizontally to those locations within the range of temperatures and humidities in the mound that provide conditions conducive to maximal growth.

Growth within a fire ant mound occurs from 75-94°F, with the total development time from egg to adult ranging from 55 days at 75°F to 23 days at 94°F. Besides optimizing development of the young, the mound also serves as a survival mechanism for adults during extremely cold and extremely hot conditions. For example, during hot, dry weather of summer, fire ant colonies may appear dead because no activity is observable after disturbance of the mound. However, the colony is probably not dead. Often, the worker ants will be several feet beneath the ground surface where cooler temperatures and higher humidity are more conducive to survival. When temperatures during winter are low, the adult workers also will be well beneath ground surface, and may even be immobilized by cold temperatures. However, as temperatures rise throughout the day, these adults, which often appear sluggish because of the cold temperatures, may be found just beneath the mound surface taking advantage of the sun's radiant energy. So, the sloping walls, sponge-like air chambers, and crust-like insulation provide a favorable environment for growth and development of the colony which would otherwise not be possible.

Foraging outside the mound - Abiotic factors also are known to affect the foraging behavior of the imported fire ant. Research indicates that most foraging occurs when temperatures at about one inch beneath the soil are between 69° and 90°F, and that no foraging occurs above 90° or below 55°F. Soil temperature has been shown to be the single most important predictor of foraging activity. Generally, humidity, soil moisture, and wind have been shown to have little influence on foraging activity. However, foraging is influenced by such biotic factors as internal needs of the colony, and availability and nutritional value of the food being foraged. Also, foraging ability is of short duration in shady habitats and higher altitudes. Season also is an important predictor of foraging. The rates decrease in late fall as does the type of material being foraged. Foraging ability is more limited by lower than by higher temperatures. Imported fire ants show a preference for foods with protein during brood-rearing periods and a preference for
carbohydrates during the winter months when broods generally are absent from the nest.

Two factors associated with climate limit the activity and distribution of the imported fire ant. These factors are temperature and water. Temperature can be divided into high and low limits and preferences, whereas the topic of water includes tolerances and preferences to free water, soil moisture, and relative humidity. The results of many of the experiments on temperature and humidity effects on fire ants have been obtained in the laboratory. Under these conditions, adjustments of the environmental conditions are easily altered and maintained for extended periods of time. Also, some parameters are easily held constant (i.e., light, food, etc.) while others are varied.

Temperature - Numerous studies on the preferred temperatures of fire ants have been conducted and the results indicate that this preference changes with the reproductive status of the colony. Worker ants not tending an egg laying queen or her brood prefer a slightly lower temperature than when engaged in those activities. Maximum brood and colony growth appears to occur at 90°F, but note that experiments reveal the preferred temperature of brood-tending ants (from a different locality than those used in the growth experiments) is 83°F. Apparently, some other parameter (i.e., food, light, etc.) can cause ants to select a temperature which is not the most conducive for colony growth and development. Or, it is possible that the ants from different localities have different preferences and requirements. This last phenomenon is little studied in the imported fire ant.

The temperature preferences of brood-tending worker ants in the laboratory differed slightly at different humidities. Ants tested at a low humidity (about 1 percent) selected temperatures at an average of 77°F, whereas ants tested at a higher humidity (near 100 percent) preferred 83°F. Acclimation to different temperatures in the laboratory (from 54° to 90°F) prior to the experiments showed no detectable differences in the ants' preferences, although ants collected in winter responded differently than those collected during the summer. Winter collected ants generally selected temperatures 2°F lower than summer collected ants.

Critical Thermal Maxima - The warmest temperatures at which an animal can move is termed the critical thermal maxima. This limit is determined in part by the age and condition of the individual. Ants maintained in the laboratory with weekly temperature reductions (an attempt to simulate approaching winter) showed no change in their critical thermal maxima. The highest average temperature at which the ants could move was 102°F, although some became immobile at a slightly higher temperature of 107°F. Obviously when summer temperatures reach over a hundred degrees the ants remain underground where it is cooler.

Heat Tolerance - Minor worker ants (the smallest workers) exposed to upper lethal temperatures in the laboratory for one hour die at approximately the same temperature, despite prior temperature conditions (thermal history). Also, the relative humidity had little effect on the lethal temperature for a one hour exposure. Ninety-five percent of the ants died at approximately 113°F, whereas only 50 percent of the ants had died on average when the temperature reached 108°F. The fact that different
humidities did not alter the survivorships reveals that the ants did not die of desiccation in the one hour exposure. The constant lethal limits, despite thermal history, indicate that the ants' ability to withstand heat does not change as the seasons change. Because the lethal temperature is only slightly higher than the critical thermal maxima (102°F), ants can move almost to the point of death, thus being able to move to a sheltered area if available.

Ants were exposed in the laboratory to low humidity (near 1 percent) at temperatures of 80°F, 90°F, and 100°F. The time it took for 99 percent of the ants to die varied with temperature and the size of the ant. The smaller worker ants survived at 80°F only half as long as the major workers which lived 18 hours. The results at higher temperatures were also notable: six and nine hours were lethal at 90°F, whereas four and ten hours were lethal at 100°F for minor and major workers. Although these studies were in the laboratory, they reveal that an ant has a limited time (less than four hours at 100°F and 1 percent humidity) in which it can exist on the ground surface without finding a protected site.

Critical Thermal Minima - Ants maintained in the laboratory with weekly temperature reductions (attempt to simulate approaching winter) showed no change in their critical thermal minima. The lowest average temperature at which the ants could move was 34°F, although some became immobile at 45°F. Although imported fire ants cease foraging at 55°F, movement within the colony and surrounding area continues until the critical thermal minima is met.

Resistance to Cold - This topic in insects has generally received considerable attention. Some insect species suffer high mortality during severe winters, and survival usually depends on the selection of favorable microhabitats and on the cold-hardiness of the overwintering stage. Cold-hardiness covers three distinct phenomena: freeze tolerance, supercooling, and cold acclimation.

Freeze tolerance is the ability of an organism to freeze without bodily injury. This phenomenon is documented from numerous organisms, but fire ants apparently do not possess this ability. Several studies in the field and in the laboratory reveal that ants frozen, even for a moment, are killed. However, fire ants do not necessarily freeze at 32°F and many become supercool without injury. Supercooling is the process by which an organism can lower the freezing point of its body below that of water. Some insects are known to produce antifreeze chemicals during the winter to lower their freezing points. Studies have revealed a noticeable difference between the supercooling abilities of imported fire ants maintained in the laboratory and those in the field. Under field conditions, ants supercooling points varied only slightly through the season, from about 21°F in October to near 25°F in February. Under those conditions the lowest point at which an ant would remain unfrozen was about 21°F, whereas in the laboratory, adult ants could be recorded surviving on an average to just above 12°F. The reasons for these differences are unknown.

Cold acclimation, or preparation to avoid injury at temperatures below those at which continued growth is possible, is most notable in the fire ants behavior, not in its physiology. No differences have been detected in the
ant's body through winter which would help it to overwinter, but the adaptations previously noted regarding mound construction and movement within the mound are methods which can be considered a form of cold acclimation. As in all cold-blooded animals, lower temperatures lead to lower metabolic rates and the reduced need for food.

An isolated population of the imported fire ant was discovered in Lubbock, Texas. This find is the most northwestern population in the U.S.A. and has survived at least four years at that locality. During the 1985/1986 winter, over 200 colonies were marked, and 85 percent of the colonies survived. During the 1986/1987 winter, almost 300 colonies were marked, and 48 percent of the colonies survived the winter season. More colonies that were located near masonry walls, concrete curbs, and other protected sites survived the rigors of winter than those in open, exposed situations. The lowest temperature reported by the U.S. Weather Service in Lubbock during those four years was 0°F. Also, approximately 70 days during the period had daily temperature minima equal to or less than 32°F. Subsurface temperatures within an imported fire ant mound were always greater than air and soil surface temperatures, although, temperatures within fire ant mounds were slightly less than a nearby soil profile, at least down to 12 inches subsurface. Fire ant mounds near a masonry wall were generally warmer at 12 inches subsurface depth than were mounds in unprotected lawns, the walls acting as solar heaters, a phenomena the ants use to their advantage.

Water and Humidity - Mounds are larger and taller in moist soils, possibly to increase evaporative surface area and allow the ants to escape high water tables. The outer surface of such mounds are generally not crustlike and are porous, allowing for considerable evaporation.

While worker ants without brood did not show marked humidity responses (preference or avoidance) in laboratory tests, brood-tending ants always selected the highest humidity levels available. This response was presumably due to the broods' higher susceptibility to desiccation. In addition, imported fire ants will not drown in heavy rains or flooding. These ants have developed a method by which they hold on to each other and float on top of the water as a ball. Floating balls of ants can be carried considerable distances down a stream or river.

In contrast, the fire ant is susceptible to desiccation when exposed to long dry conditions. Up to 70 percent mortality of imported fire ant colonies has been reported from an extreme summer drought in southeastern Texas, but in that situation the colonies were possibly monogynous (one queen per colony). Many colonies are now known to be polygynous (more than one queen per colony) and in polygynous colonies a high mortality of queens may not result in a noticeable reduction in number of mounds.

Immobility (such as the critical thermal maxima and minima) should not be confused with death. While the average critical thermal maxima and minima of ants are 102° and 34°F, the average lethal temperature for short term exposures are 113° and 21°F. In summary, the following temperature limits and preferences are known for the imported fire ant:
113 °F average lethal temperature for short exposures
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102 °F average critical thermal maxima
99 °F upper foraging limit
94 °F upper limit for window of growth within a colony
90 °F maximum brood and colony growth
83 °F preferred temperature at high humidity
77 °F preferred temperature at low humidity
75 °F lower limit for window of growth within a colony
55 °F lower foraging limit
44 °F upper range of critical thermal minima
34 °F average critical thermal minima
32 °F water freezes - - - - - - - - -
- - - death - - - - - - - - - - - - -
21 °F average supercooling point of field ants
12 °F average supercooling point of laboratory ants

The distribution of the red imported fire ant, and the factors which might limit its spread across Texas have received considerable attention in recent years. Since 1953 when the imported fire ant entered Texas, 112,145 square miles have become colonized. The rates of spreading have increased, reaching a maximum of 7,472 square miles per year during 1973 to 1977. Although the rate of spreading decreased between 1977 and 1983, the rate since 1983 has increased. The erratic changes in colonization rate are presumably due to the jump and range consolidation method of invasion and the effort, by humans, to control the spread of the imported fire ant. The rate (cumulative area/time) of spreading has remained constant with changes in the increment rates being minor, when compared to the total areas already colonized.

Numerous predictions on the future range of the imported fire ant have been proposed. Some predictions have been based on comparisons to the known distributions of related fire ant species. Other predictions were based on movement records from previous years. The primary methods of dispersal are mating flights, floating on flood water, and transport by humans. Though most mated queens established colonies within one mile of the nuptial flight origin, they can fly or be carried by winds for ten miles. The rate of spread in Texas was approximately 30 miles per year from 1957 to 1977, but after that the rates have differed. Researchers included previous distribution patterns in a modeling technique to analyze the spread of the imported fire ant and to make predictions for its future range. They noted that from 1965 to 1976, the imported fire ant increased its climatic space to include areas that were both warmer and drier than the areas occupied prior to 1965. They indicated that until the species encountered some environmental resistance, it would continue to spread into hot, dry areas and predicted that by 1986 the species would be found in almost all the counties east of the Pecos River and south of the 0°F January isotherm in Texas. Although many factors affect the rate of spread of the imported fire ant, human transport appears to be the most significant factor in long
distance expansion. The predictions proposed and rates stated by previous workers now all appear incorrect. In most cases, the projected ranges exceed the actual distributions, suggesting that the rates of spreading have decreased.

The ultimate range of the fire ant in Texas has not been determined. Relative aridness in western Texas may prevent fire ant colonization and the 10°F January isotherm may be the limit for survival in that part of Texas known as the Panhandle.