

Distribution of the Red Imported Fire Ant *Solenopsis invicta* (Hymenoptera: Formicidae) in Central Florida Pastures

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Abstract

Habitat disturbance has been found to facilitate the introduction of a wide range of species, including the red imported fire ant *Solenopsis invicta* Buren (Hymenoptera: Formicidae: Myrmicinae). Despite the link between *S. invicta* colonization and disturbance, little is known about how different intensities or types of disturbance might impact *S. invicta* populations. In this study, we used *S. invicta* populations in cattle pastures to understand how variation in disturbance type and frequency correlates with the density of *S. invicta* mounds. In total, 56 plots were surveyed for mound abundance during both the wet and dry seasons on a subtropical south Florida ranch. Explanatory variables were grouped into five categories based on disturbance type: 1) historic pasture conversion; 2) modern pasture management (mowing, dragging, chopping, or aerating); 3) grazing intensity (a measure vegetation height and dung pat abundance); 4) distance to human-made and natural localized disturbance (roads, ditches, and wetlands); and 5) abiotic conditions (soil temperature, soil moisture). Overall, the average number of mounds per plot was not significantly different between seasons, but was significantly higher in intensive pastures, which are converted to nonnative forage grasses than in seminative pastures during the dry season. Time since soil disturbance (aeration and chopping of pasture) was a significant predictor of *S. invicta* densities in both dry and wet seasons, with an increase in time since disturbance being associated with higher mound densities. Other forms of pasture management that did not disturb the soil, such as dragging and mowing, as well as distance to localized disturbances (wetlands, roads, and ditches) were not found to have a significant correlation in either season.

Key words: agroecology, red imported fire ant, invasive species, disturbance

Anthropogenic habitat disturbance is one of the most important drivers of biodiversity change and has been found to facilitate the introduction of a wide range of species, including the red imported fire ant, *Solenopsis invicta* Buren (Hymenoptera: Formicidae: Myrmicinae) (Wilson 1951, Tschinkel 2006, King and Tschinkel 2008). Of the habitat types typically occupied by *S. invicta* throughout their invaded range in the United States, pasture environments have been found to house their highest population densities (Porter et al. 1997). In pastoral systems, anthropogenic disturbances such as mowing, tilling of soil, and vegetation removal may occur alongside disturbances that mimic natural processes such as seasonal flooding and fire. While these disturbances differ in their origin (anthropogenic vs natural), they also vary in their ability to impact the above and belowground structure of the prairie, creating a mosaic of disturbed habitat types. Although a link between anthropogenic disturbance and *S. invicta* colonization and persistence has been observed (Tschinkel 2006; King and Tschinkel 2008, 2013, 2016), little

is known about how the type and intensity of disturbance impact the ability of the species to colonize and persist within its invaded range.

One of the few experimental studies to specifically investigate the role of disturbance on persistence was conducted by King et al. (2008) and utilized relatively pristine, uninvaded pine flatwoods in Florida. Experimental plots in these sites were mowed, plowed or unaltered and received either an addition of mature *S. invicta* colonies or no ant addition at all. While *S. invicta* persisted in all plots where colonies were added, survival and growth were highest in plots disturbed through mowing or plowing. At the end of the experiment, treatments to plots ended while monitoring continued, and abundances were found to decline over time. This suggests that, within that system, both the invasion and persistence of *S. invicta* is dependent upon the sustained intensity of disturbance.

In addition to large-scale disturbances such as plowing or mowing, several studies have also shown that even areas of localized disturbance within a habitat, such as roadsides, can increase habitat

quality for *S. invicta* (Stiles and Jones 1998, Forsys et al. 2002, Kelly and Sellers 2014). In the Florida Keys in the late 1980s, the density of *S. invicta* was relatively low, as invasion had not yet occurred on every island (Porter 1992). By 2002 a study by Forsys et al. found high densities primarily concentrated along roadways and in edge habitats in every Key. Furthermore, undisturbed sites were more likely to be occupied if they were within 50 m of a road and within 150 m of high densities of urban development, demonstrating that these patches of localized, persistent disturbance adjacent to roadways served as sites for the persistence and dispersal of *S. invicta* colonies.

Of disturbed habitat types typically occupied by *S. invicta* throughout their invaded range in the United States, pasture environments present an excellent study system for determining the relationship between ant densities and disturbance type. Not only are *S. invicta* colony densities highest in pastures (Porter et al. 1997), they are also subject to a wide array of disturbance types (soil disturbance, mowing, roads, wetlands etc.) applied at varying intensities and frequencies. Included in these disturbance types are the uniquely pastoral impacts of livestock trampling and grazing activity. Tucker et al. 2010 found that there were more *S. invicta* workers at baits in grazed pasture areas than areas where grazing was prevented. However, the mechanism by which grazing might influence *S. invicta* density is not clearly understood. Bremer et al. 2001, found that evapotranspiration within pasture soils decreased in response to grazing, thereby increasing soil moisture. Grazed pastures may, therefore, provide the increased soil moisture levels preferred by *S. invicta* (Xu et al. 2009).

While densities of *S. invicta* have been found to be associated with the presence of disturbance in general, disturbance occurs along a spectrum that may vary in both intensity and frequency resulting in shifts in abiotic and biotic factors both above and below ground. Here we used *S. invicta* populations in cattle pastures to understand how different types of disturbance created through pasture management decisions and other habitat-scale disturbances, correlate with the density of *S. invicta*. We hypothesized that if habitat disturbance is the primary driver of *S. invicta* density, then density will be positively correlated with variables related to the degree of disturbance. The overarching goal of this research is to determine which forms of disturbance are associated with high densities of *S. invicta* colonies, in highly disturbed ecosystems. To accomplish this, we measured *S. invicta* mound density, across a range of environmental conditions on a south-central Florida cattle ranch. Explanatory variables were then grouped into five categories based on disturbance type:

- (1) historic pasture conversion (conversion of native habitat to semi-native or intensive pasture)
- (2) modern pasture management (mowing, dragging, chopping, or aerating)
- (3) grazing intensity (average vegetation height and number of cow dung pats)
- (4) distance to human-made and natural edge habitat (roads, ditches, and wetlands)
- (5) abiotic conditions (soil temperature, soil moisture)

Materials and Methods

Study Site

The study was conducted at Archbold Biological Station's Buck Island Ranch (hereafter BIR) a 4,170-ha commercial cattle ranch, with approximately 3,000 cow-calf pairs located in Lake Placid, Florida. The subtropical climate has distinct wet (May–October)

and dry season (November–April) and an average annual rainfall of ~130 cm. Most soils at BIR are poorly drained, acidic, sandy spodosols, alfisols, and entisols. BIR is divided approximately 50:50 into two pasture types: intensively managed and seminatural. Intensively managed pastures are planted with introduced Bahia grass (*Paspalum notatum*) and have been fertilized annually with NPK fertilizer for 20+ yr prior to 1987. They have been fertilized only with N annually since 1987. In contrast, seminatural pastures are not known to have ever been fertilized and are dominated by native grasses, such as bunchgrasses, (e.g., *Andropogon virginicus* and *Panicum* spp., *Axonopus* spp.). *S. invicta* colonies are commonly found throughout both pasture types. Fire ant populations at BIR appear to be dominated by the single-queen social form (monogyne) based upon hap-hazard observations of worker size distributions and the low density of colonies (Porter et al. 1991).

Sampling

From 34 pastures available in the northern section of BIR, eight pastures were selected (four each in seminative and intensively managed pastures) to conduct *S. invicta* surveys. Because *S. invicta* density has been found to increase with increasing human disturbance, plots within pastures were placed using stratified random sampling by disturbance (i.e., proximity to road) (King and Tschinkel 2008). Approximately one-third of the plots were placed in areas along roadways, which were predicted to house a high density of *S. invicta* (Forsys et al. 2002). The remainder of the sites were randomly located within the pasture. Additionally, the number of plots within a pasture was based upon pasture size (1 per 100 hectares).

In total, 56 plots were surveyed twice across the eight pastures. Each plot was 26 × 26 m in size and was searched entirely for fire ant mounds. Surveys consisted of walking 13, 2 m wide transects across each plot while scanning for mounds. Surveys were first conducted in January of 2014 and then repeated in May of 2014. During each sampling event abiotic variables, vegetation height and number of dung piles within a 2 × 2 subplot at the center of the plot, were recorded. The distance of each plot to the nearest road, wetland, and ditch was then determined using maps of landscape features created by Archbold Biological Station with ArcMap 10.2.2.

The management history for each pasture was also collected from a database developed at BIR known as PastureSTAR. The date and percentage of pasture covered by the management activity are recorded in PastureSTAR for the following activities: mowing, dragging, roller chopping, and aerating. Mowing of pastures usually involves cutting vegetation to 15 cm in height or shorter in order to promote the growth of grass and reduce the growth of forbs and woody vegetation. Dragging involves utilizing a tractor to pull weights (often tractor tires) through the pasture in order to physically break apart dung pats on the surface of the pasture. This too is done in order to promote the growth of forage grasses. Roller chopping and aerating are similar in that they both utilize a tractor attachment designed to disturb the surface of the soil. An aerator attachment is a large roller with spikes that is used to puncture the surface of the soil while a roller chopping attachment utilizes blades instead of spikes designed to cut vegetation near the surface of the soil. Although roller chopping is used for vegetation management, it often disturbs the first 5–15 cm of soil. While soil disturbance has been found in several studies to be an important habitat variable that promotes *S. invicta* establishment (Stiles and Jones 1998, King and Tschinkel 2008, LeBrun et al. 2012), the less invasive activities of mowing and dragging may also increase habitat suitability (King and Tschinkel 2008).

Analysis

The response variable analyzed was the total number of active *S. invicta* mounds per plot. The data collected for this study were nested at two different levels. The primary units were pastures, which were randomly selected from larger blocks of pasture type (semimative vs intensive). Randomly located plots were then sampled within each pasture. Due to the hierarchical design of the study and the count response variable, generalized linear mixed models were utilized with negative binomial distributions and 'Pasture' assigned as a random factor (Zuur et al. 2009). Dry season (January) and wet season (May) surveys were analyzed separately due to previous evidence that fire ant densities vary with season and because of differences in the abiotic variables collected in each season (Porter and Tschinkel 1987, Porter 1988).

Modern pasture management variables were analyzed individually as well as grouped into two categories based on soil disturbance: 1) Ground surface disturbance (mowing and dragging) and 2) Soil disturbance (aeration and chopping). These categories were used to determine whether the individual activity versus the type of disturbance was significant in altering ant mound distribution. All pasture management variables were measured based on both the type of activity (i.e., mowing, dragging, aeration, or chopping) and the amount of time from 2014 since the management activity. For example, mowing a pasture in 2009 was recorded as 5 yr since mowing activity, while mowing in 2013 was recorded as 1 yr since mowing activity. This produced a time gradient for management activity across pastures ranging from 0 to 5 yr.

Overall, a priori hypotheses were used to group the 10 explanatory variables into five categories. These included: 1) historic pasture conversion (semimative or intensively managed), 2) modern pasture management (mowing, dragging, chopping, or aerating), 3) grazing intensity (average vegetation height and number of cow dung pats), 4) distance to human-made and natural habitat features (roads, ditches, and wetlands), 5) abiotic conditions (soil temperature for the dry season data, soil moisture for the wet season data). Collinearity among predictor variables was assessed and no correlation coefficients were greater than 0.75, therefore, no variables were omitted.

Due to the large number of variables and the large number of potential models that could be created, a procedure adopted from the collective works of Zuur was used to reduce the model set (Zuur et al. 2007, 2009, 2010). After constructing the five hypotheses categories, 10 possible two-way interactions were added based on a priori biological knowledge. For example, an interaction between the pasture type (semimative vs. intensive) and vegetation height was included because grazing intensity (represented by vegetation height) may result in nontangential shifts in plant community composition in semimative vs intensive pastures (Boughton et al. 2011). Within each hypothesis category, models were constructed by means of maximum likelihood (ML) and the lowest Akaike Information Criterion, corrected for small sample size (AICc) was used to select the best-fitting model (Burnham and Anderson 2002). After examining the models for each hypothesis group, models with AICc values lower than the null were then combined across hypotheses groups to produce the final model set. This process generated 15 possible models for the wet season data and 32 for the dry season data. For each of these models, the statistical significance of the fixed effects was determined using Wald χ^2 tests. Post-hoc mean comparisons were performed using Tukey's honestly significant difference (HSD) test. Pearson residuals were plotted against fitted values for *S. invicta* mound abundance to visually check for homogeneity of variance and normality of data (Zuur et al. 2009). All statistical tests were performed in the R program (version 3.1.1; R Development

Core Team 2014, Vienna, Austria). The package ADMB was used to perform GLMMs, AICc comparisons were conducted using package 'bblme' (Bolker 2011), and significance tests with package 'car' (Fox and Wiesberg 2019). Graphs for publication were created using the program Origin Pro.

Results

Of the 57 plots sampled in the wet season and dry season, only two were found to be devoid of *S. invicta* mounds (Fig. 1). The average number of mounds per plot was not significantly different between seasons but was slightly higher in the wet season (5.73 mounds/plot, SE = 0.60) than in the dry season (4.63 mounds/plot, SE = 0.474). While mounds were more abundant in intensive pastures in both seasons, the relationship was only statistically significant in the dry season (5.84 mounds/plot, SE = 0.821 in intensive pastures versus 3.65 SE = 0.474 in semi-native pastures, Tukey's HSD, $P = 0.01982$).

Overall, of the fixed effects found to have a significant effect on *S. invicta* mound abundance, only time since soil disturbance (aeration and chopping) was a significant predictor in both dry ($df = 5$, $P = 0.0098$) and wet ($df = 5$, $P = 0.0020$) seasons, with an increase in time since soil disturbance being associated with higher mound densities (Table 1; Fig. 2). Other forms of pasture management that did not disturb the soil, such as dragging and mowing, were not found to be significant in either season. Within the dry season, the interaction between pasture type and vegetation height significantly impacted the number of mounds per plot. For the wet season data, the number of dung pats per plot was significant, with more dung pats associated with a greater number of ant mounds. The results by season are discussed in greater detail below.

Dry Season Data

For the dry season data set, the following variables were within the top models from each hypothesis category and were used to construct the final set of models: number of dung pats per plot (Dung), vegetation height (Veg), time since soil disturbance (TSA_C), time since mowing or dragging of pasture (TSM_D), pasture type (Type), and an interaction between the pasture type and the height of vegetation (Type:Veg) (Table 2). Notably, none of the models containing the distance to localized disturbance variables were found to possess more predictive power than the null model. Of the 32 possible models created for the dry season data set with these variables, the top seven were nearly indiscriminate in their delta AICc values and weights. However, all seven top models included the variables TSA_C + Type:Veg and, therefore, this was selected as the most parsimonious model. Both TSA_C (Wald $\chi^2 = 6.68$; $df = 1$; $P = 0.0098$) and Type:Veg (Wald $\chi^2 = 9.11$; $df = 1$; $P = 0.0025$) were also found to be significant within the model (Table 3). Time since soil disturbance was positively correlated with mound density, with fewer mounds in more recently disturbed pastures. There was a significant interaction between pasture type and vegetation (Type:Veg). Graphing of this relationship found that there was no effect of vegetation height on mound abundance in improved pastures, while in semimative pastures, the number of mounds was negatively correlated with vegetation height.

Wet Season Data

For the wet season dataset, the following variables were within the top models from each hypothesis category and were used to construct the final set of models: number of dung pats (Dung), time since soil disturbance (TSA_C), pasture type (Type), and an interaction between the time

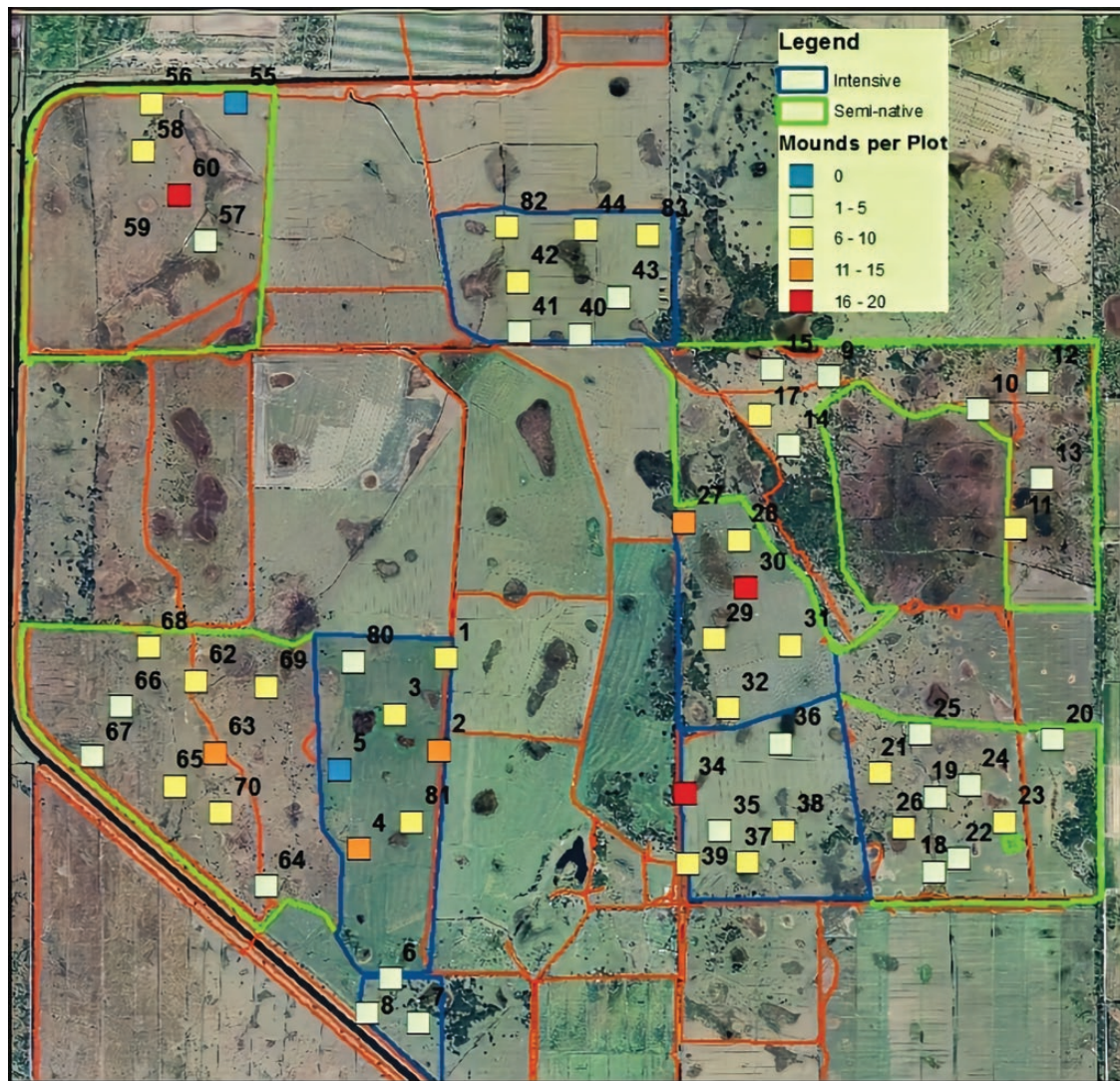


Fig. 1. Map of the densities of *S. invicta* within each plot sampled during both the wet and dry season sampling events.

since aeration or chopping and pasture type (TSA_C:Type) (Table 4). Similar to the dry season data, distance to localized disturbance was not found to possess more predictive power than the null model. Of the 15 possible models created with these variables, the model that included the number of dung pats per plot (Dung) and time since soil disturbance (TSA_C) was selected as the top model as it had a weight nearly triple that of the next most plausible model. Both number of dung pats per plot (Wald $\chi^2 = 4.38$; df = 1; $P = 0.0363$) and time since soil disturbance (Wald $\chi^2 = 9.59$; df = 1; $P = 0.0020$) were found to be significant within the model (Table 5). The average number of mounds per plot increased as both the time since soil disturbance increased and as the number of dung pats increased.

Discussion

Time Since Soil Disturbance (Aeration or Chopping)

This study found that time since soil disturbance was correlated with both dry season and wet season *S. invicta* mound density. Mound densities were lowest in sites with less time since disturbance and steadily increased as time since soil disturbance increased from 1 to 5 yr. This parallels results from a study by LeBrun et al. 2012 in which

the prevalence of *S. invicta* was assessed in Texas pastures from approximately 3 to 35 yr after an initial soil disturbance. As in the current study, LeBrun found that *S. invicta* abundances were highest approximately 3–5 yr postdisturbance. Additionally, abundances were found to gradually decline as pastures recovered and time since disturbance increased to 35 yr. Thus, *S. invicta* abundances in response to soil disturbance over time likely take on a bell-shaped response, with abundances declining in the first 0–1 yr after disturbance, and then increasing exponentially and reaching a maximum at 3–5 yr post disturbance before beginning to decline.

The observed decline in *S. invicta* colony abundance in the first year after disturbance may potentially be related to the physical destruction of existing mature colonies, whose survival is dependent upon building an aboveground mound structure (Tschinkel 2006). The disturbance likely also creates a visual cue that is attractive to newly mated queens seeking to start new colonies in the spring and summer following disturbance (King and Tschinkel 2016). An influx of new colonies, and *S. invicta*'s proclivity for rapid growth postsoil disturbance (Tschinkel and King 2017), may then lead to an expeditious rise in the number of *S. invicta* colonies within the disturbed habitat. The 5-yr peak in *S. invicta* mound abundance correlates

Table 1. The number of sites sampled within each factor level for the variable ‘Time Since Soil Disturbance’

Time since soil disturbance (aeration or chopping)	Number of sites sampled
1	35
2	9
3	0
4	6
5	6

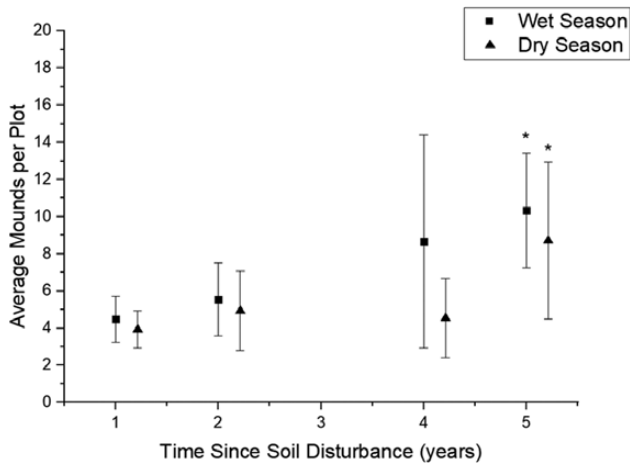


Fig. 2. Number of mounds in plots that had been aerated or chopped 1, 2, 4, and 5 yr prior to the sampling event. No plots were aerated or chopped in 2012, resulting in no measurements for 3 yr since disturbance. Error bars were constructed using 95% confidence intervals.

Table 2. All models for the dry season data with a difference between the lowest AICc value and AICc of 2 or less

Model	Log(L)	AICc	ΔAICc	Df	Weight
TSA_C + Type:Veg + Dung + Veg	-131.0	278.3	0	7	0.1100
TSA_C + Type:Veg	-133.8	278.8	0.5	5	0.084
TSA_C + Type:Veg + Dung	-132.6	278.9	0.6	6	0.0827
TSA_C + Type:Veg + Veg	-133.1	278.9	0.6	6	0.0811
TSA_C + Type:Veg + TSM_D	-133.3	280.0	1.6	6	0.0489
TSA_C + Type + Veg	-132.1	280.4	2.0	6	0.0396

The following variables were used for model construction: Dung (number of dung pats per plot), TSA_C (time since soil disturbance/aeration or chopping of pasture), Veg (average vegetation height within each plot), TSM_D (time since mowing and dragging of pasture), and Type:Veg (an interaction between the pasture type and average vegetation height per plot). Log(L) = maximized log-likelihood, K = number of parameters, AICc = Akaike information criterion value, ΔAICc = differences between the lowest AICc value and AICc i, AICcWt = model weight.

with the peak size of individual colonies (Tschinkel 2006). After a queen has selected a new location to begin building her colony, studies of colony growth have found that within 4–6 yr the colony will have reached its maximum size of approximately 200,000 workers (Tschinkel 1988). Thus, high densities may result from the coupled impact of an influx of new colonies and the survival and reestablishment of existing colonies.

Furthermore, the apparent dominance of monogyne colonies across the landscape at BIR may also contribute to the observed

Table 3. Summary of results from the top model for the dry season data set: Type:Veg + TSA_C. **P < 0.01

	Estimate	Std. error	Z value	Pr(> z)
(Intercept)	1.49077	0.17669	8.44	<2e-16
TSA_C	0.15149	0.05862	2.58	0.0098**
Type:Veg	-0.00879	0.00291	-3.02	0.0025**

decline in mound densities after an initial peak. Young populations of monogyne colonies reach peak densities the first year after mass founding events, then as larger colonies establish territories and absorb or kill smaller colonies, the density of nests decline over the following years (Tschinkel 2006). If small areas of pasture have not been disturbed for a long period of time, it is also possible that colony densities may become very low or zero for small areas as colonies senesce and die and are not replaced. This may be why we observed two (out of 57) plots without any fire ants. These results reinforce the repeated general observation that *S. invicta* achieves its highest densities in anthropogenic habitats (Tschinkel 2006). Additionally, results suggest that even within anthropogenic habitats population densities will vary locally and will tend to be highest where soil disturbances are frequent and recurring (King and Tschinkel 2008, Lebrun et al. 2012).

Vegetation Height and Dung Pat Abundance: One and the Same?

In agricultural studies, vegetation height is often used as a measure of grazing intensity due to the patchiness of livestock grazing activity within pastures. However, in seminative pastures where species composition (and therefore vegetation height) may vary greatly within and between pastures, another method of estimating grazing intensity across pasture types was needed. Thus, as previously described in the methods, we counted the number of cattle dung pats found within a 4 m² area of the plot as a proxy for local grazing intensity. We found that, in general, as the vegetation height increased, the number of dung pats declined, which would indicate lower grazing activity in the area around the plot. However, the number of dung pats within a plot proved to be a significant variable for the wet season data, while vegetation height did not (Fig. 3). This may be because dung pats are not only an indicator of grazing intensity, but also provide an additional benefit to *S. invicta* in the form of moisture refugia, protection from temperature extremes and a foraging site.

During sampling, it was anecdotally observed that many of the dung pats themselves were home to entire colonies of *S. invicta*. It is possible that even in mesic pastures, dung pats provide shelter for colonies as the hardened crust of the pat reduces water loss from the inner portions of dung and may modulate temperature fluctuations. Furthermore, pats are home to the larvae of numerous species of dung breeding flies as well as adult and larval dung beetles. The concentration of these organisms in the small area of a dung pat likely provides an easily foraged source of food (Summerlin et al. 1984a, b). Further investigation of the relationship between *S. invicta* and dung pat usage is necessary to determine how colonies may be utilizing dung pats in pastures to maintain high abundances.

Interaction Between Pasture Type and Vegetation

Only the dry season data showed a significant impact of the interaction between pasture type (Type) and vegetation height (Veg) on *S. invicta* densities. Overall, mound densities during the dry season were highest in intensive pastures at moderate vegetation heights. It is possible that, although low vegetation heights in intensive

pastures would indicate a high level of grazing disturbance, the lack of precipitation during this season results in more rapid desiccation of soils, resulting in moisture limiting the growth of colonies. Conversely, the colonies may be present in these plots, but due to the high frequency of disturbance in heavily grazed pastures, they may not be creating mounds. This has been observed in other subtropical locations in Florida (Tschinkel 2006).

Non-significance of Abiotic Variables and Distance to Edge Habitat

Despite evidence in the literature for the importance of soil temperature and soil moisture on *S. invicta* foraging and nest construction (Porter and Tschinkel 1993; Vogt et al. 2003), neither were found to be significant predictors of density at the scale of our study. This may be related to the relatively warm and moist conditions at nearly all

Table 4. All models for the wet season data with a difference between the lowest AICc value and AICc of 2 or less

Model	Log(L)	AICc	Δ AICc	df	Weight
Dung + TSA_C	-144.7	300.7	0	5	0.242
Type + Dung + TSA_C	-144.4	302.6	1.9	6	0.091
TSA_C	-147	302.7	2	4	0.087

The following variables were used for model construction: Dung = number of dung pats per pasture, TSA_C = time since chopping and aeration of pasture, and Type = pasture type (semi-native or intensive). Log(L) = maximized log-likelihood, AICc = Akaike information criterion value, Δ AICc = differences between the lowest AICc value and AICc i , AICcWt = model weight.

Table 5. Summary of results from the top models for the wet season data set: Dung + TSA_C. * $P < 0.05$, ** $P < 0.01$

	Estimate	Std. error	Z value	Pr(> z)
(Intercept)	0.9146	0.2466	3.71	0.00021
Dung	0.0515	0.0246	2.09	0.03632*
TSA_C	0.2146	0.0693	3.1	0.00195**

sites, regardless of plot or pasture. Subtropical climate and relatively consistent temperature and moisture conditions make these habitats broadly favorable for *S. invicta* (Tschinkel 2006). The low elevation of the study site meant that not only were there over 600 wetlands within the boundaries of its 10,000 acres, but much of the pastures themselves flooded seasonally. This may create such a homogenously moist environment that soil moisture and distances to water sources such as wetlands and ditches were of little significance. Although previous studies in Florida have found roadsides to be prime habitat for *S. invicta*, the less frequently traveled dirt roads within the pastures of the study site were likely not significantly different enough from the surrounding pasture habitat to increase suitability.

Conclusion

Overall, within the wet cattle pastures of south Florida, fluctuations of *S. invicta* density appears to be primarily driven by the recent history of soil-disturbing management activity within a pasture. Aeration and chopping of pastures disturbs the first 5–15 cm of soil, resulting in an exponential increase in *S. invicta* colonies from 1 to 4 or 5 yr postdisturbance. If suppressing *S. invicta* is of interest to ranchers, alternative methods of controlling woody vegetation and increasing nutrients within soil should be considered. The most viable alternative in this practice would be prescribed burning, which functions similarly to chopping in its ability to reduce woody vegetation and may not invite high levels of dispersal and colonization by fire ant queens (King and Tschinkel 2016) relative to mechanical disturbance. Although the relationship between burning and *S. invicta* density is not entirely clear, a study by Hale et al. (2011) demonstrated a reduction of *S. invicta* in burned areas. In systems with natural burn intervals, such as the wet and dry season prairie of this study, utilizing prescribed fire may both suppress *S. invicta* and improve overall ecosystem health. Continued research into the success of prescribed fire in maintaining low densities of *S. invicta* is needed in order to determine its efficacy in comparison to mechanical management methods.

Beyond the impact of mechanical treatments, high grazing intensity measured in terms of dung pat density, likely provides a disturbance that promotes high *S. invicta* density. Thus,

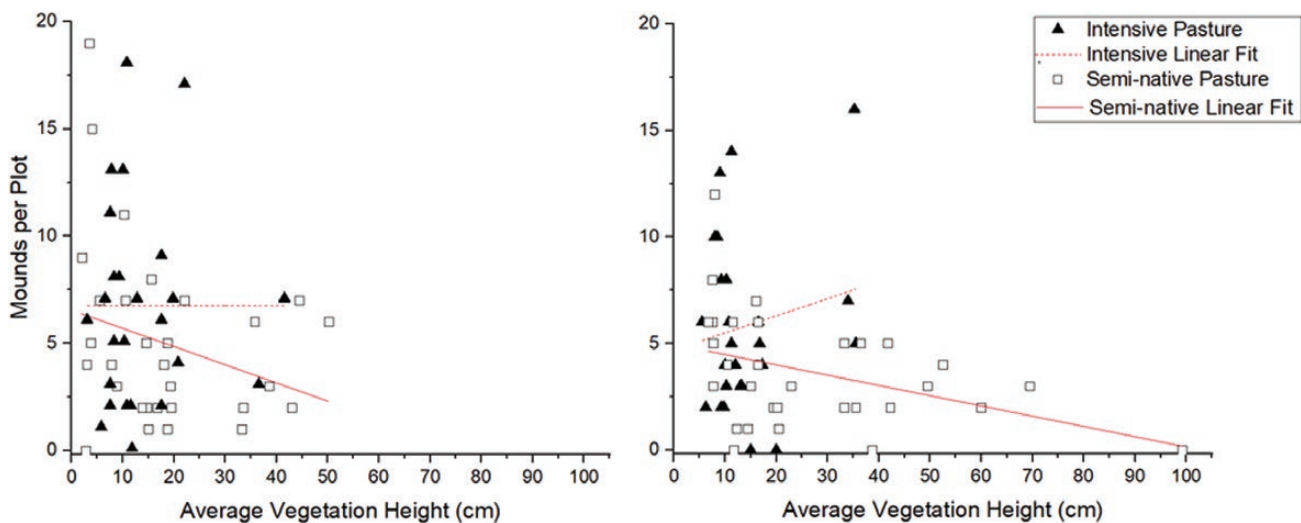


Fig. 3. Vegetation height and number of mounds within each pasture type during the wet season (left) and the dry season (right). In the dry season, the relationship between vegetation height and dung pat abundance within plots is positive in intensive pastures and negative (as expected) in seminative pastures. However, the relationship between vegetation height and dung pat abundance is diminished during the wet season and dung pats become a significant predictor of *S. invicta* mound abundance.

maintaining stocking densities that maintain dung pat densities below the mean produced by this research (5.7 pats per 4m²) may aid in reducing *S. invicta* densities. However, it should be noted that because the measurements of mound abundance were collected within a single year, instead of across multiple years, results should be interpreted with some caution. Of the environmental variables collected for the study, many, such as soil temperature and vegetation height, are likely to vary greatly between years which could result in shifting abundances. Future research should investigate the role that dung pats, and other temporary refugia (i.e., human structures or roadsides), play in favoring *S. invicta* in invaded ecosystems.

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