

Antlions' Group Distribution and Behavior under Varying Spatial Constraints

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Source Code

Report Full Text

Essential Question and Hypothesis

Essential Question:

How do antlion spatial patterns, such as pit depth, width, and nearest neighbor, as well as behaviors, such as cannibalism and eating habits vary with respect to spatial constraints and temporal change?

Hypothesis:

As the space available to antlion groups decreases, each claims less territory, and the populations tend towards more extreme behaviors, such as cannibalism and reclusivity, to limit competition for ants as an emergent feature of individual interactions.

Abstract

The experiment aimed to examine the spatial and behavioral interactions between antlions (*Myrmelcon immaculatus*) as the space they had to distribute themselves decreased. Throughout the experiment pit depth, width, location, and cannibalism were measured. This was done by placing antlions in an enclosure and recording their settlement patterns and behaviors, then by reducing the habitat size of the antlions over time to examine changes in position and interaction. Lastly, a python program was made to analytically compare the data and create graphical representations of the data, such as voronoi diagrams. It was hypothesized that cannibalism would increase and that pit depth and width would change proportionally to the environment. The hypothesis that they exhibit more extreme behaviors under space constraints was confirmed because, proportional to the number introduced, especially in the 8x7 trial, as cannibalism and non-formation of pits increased significantly—likely as a compensatory mechanism to ensure that a stable “surface group” could still safely exist. Additionally, territory (measurable by the Voronoi diagrams and by nearest neighbor) decreased towards the later trials, and the patterns did not merely display the same structure scaled down—rather, antlions accepted more dense conditions by increasing pit density. This likely corresponds to natural conditions (especially in hatcheries) where some proportion of the antlions remain on the surface (increasing with population density because it's understood to mean a prevalence of food), and as the surface antlions become adults (sometimes fed through cannibalism), new larvae emerge to take their place and sustain the species' propagation.

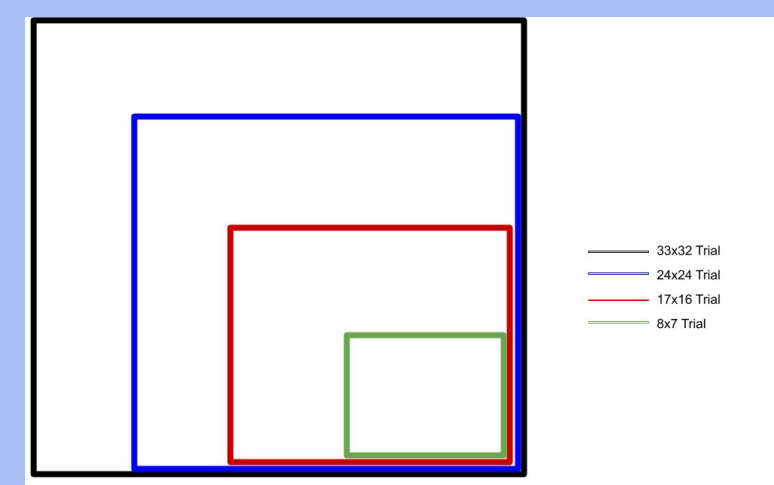


Fig 1: The relative sizes of each trial



Fig 2: A 3cm antlion pit

Background Information

To design the experiment and understand the organisms' underlying behaviors which might affect it, extensive background research was required—specifically on their spatial distribution patterns. First, a previous study analyzing the spatial patterning and structure of termite mounds in an African savanna was examined to better understand the procedure of the experiment. This study examined how different termite colonies in the African savanna positioned themselves in relation to one another, and uncovered that termite mounds each neighbor six other termite mounds at a relatively constant distance, creating uniform hexagons of termite mounds through the savannah. Furthermore, this study uncovered that termite mounds must maintain a constant distance from each other to prevent conflict between termite colonies, which would limit the overall success of the species. These results helped guide and shape this study that was conducted by providing insight to the possible intraspecific competition that could result from close antlion contact, leading to the prediction that antlions (*Myrmelcon immaculatus*) would have to space themselves in order to prevent competition for food. Lastly, this study determined that a change in available space could affect the spatial patterns of termites as well as their behavior, which was later used in designing the conducted experiment.

Next, several studies regarding the anatomy and behavior of antlions were used in order to better understand the insects. These studies determined that antlions stay in their larva form, in which they make pits, for 6-8 weeks and develop slower when exposed to less food. This helped determine the timeline of the experiment and determine the intervals at which the antlions would be fed, as in order to keep results consistent the antlions would have to be the same throughout the course of the experiment, which would require the participating antlions to be fed less in order to stay in their larva stage to make pits. Furthermore, these studies examined terms such as pit depth and width as well as the feeding patterns and behaviors of antlions, which became crucial areas of study throughout the experiment, as these studies determined that pit depth and width can signify the dominance and success of antlion settlement. This helped determine the dependent variable—size/density constraints—to examine over the course of the study. Finally, these studies determined that antlions have a tendency to cannibalize each other in times of food shortage and significant competition. This provided another dependent variable to track over time and examine as size decreased, as cannibalized antlions were unsuccessfully metabolized and evident in pits.

Lastly, a series of studies about antlion dispersal pattern called the “Doughnut theory” were examined to better understand the current scientific knowledge surrounding antlion dispersal patterns. These papers determined that antlions naturally position themselves in a “doughnut,” in which a ring of antlions circle a center point or food source to limit competition for ants, as each antlion has equal access to the food source. This study also concluded that when antlions are introduced one by one the same results occur, which confirmed that the procedure could introduce one antlion at a time without interfering with results and spatial patterns, helping further perfect and standardize the procedure, as well as provide a better understanding of antlions behavior patterns. These studies provided a better understanding of antlion settlement patterns and gave a guideline for what to expect as trials continued. Finally these studies provided scientific procedures that could be tested and confirmed throughout the experiment, allowing for a source to cross-check results and procedures with in order to perfect the procedure of the experiment.



Fig 3: An antlion being pulled out of the 8x7 enclosure

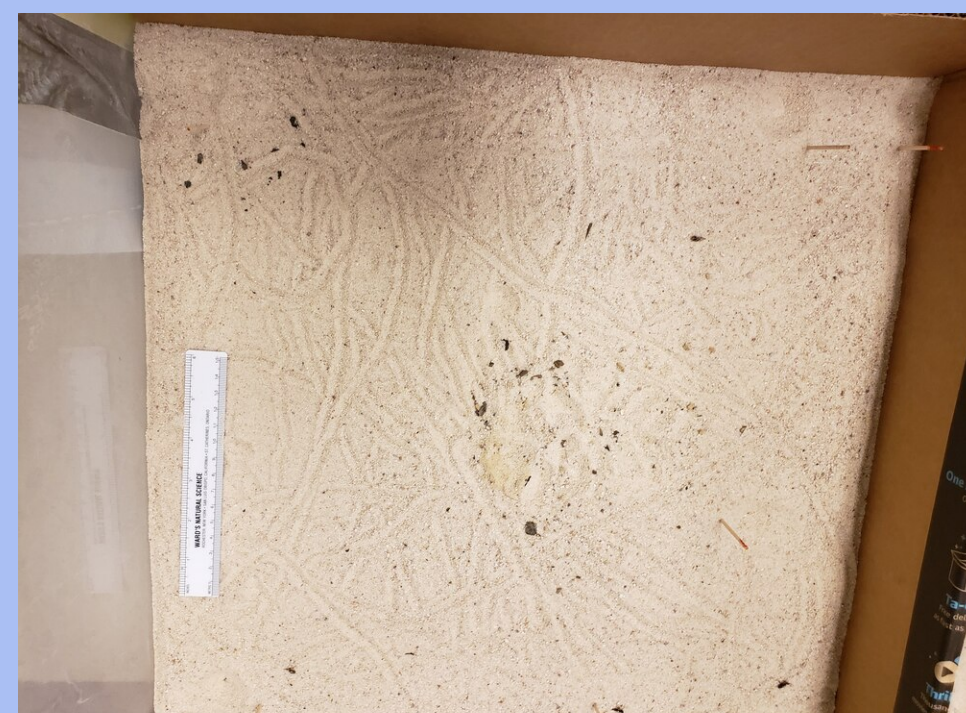


Fig 4: A number of lines formed by wandering antlions determining density

Materials

First, a 32x33 container was used to house antlions. A cardboard barrier (and sufficient tape) was constructed to restrict it to a 24x24, 16x17, and 8x7 spaces. Approximately 200 pounds, or four 50lb bags, of quartz sand were needed as a substrate. Next, 40 antlions were obtained and 160 ants for food. 40 plastic circular containers (at a six inch diameter and a four inch depth) housed the antlions and 1 housed the ants. One meter stick, a six inch ruler, and a sharpie were obtained to measure and obtain data from trials. Then, 40 toothpicks and a small plastic cup with a diameter of 2 inches were applied to record and manage the locations of antlions throughout the study. A sieve was used to move the antlions from place to place and secure them.

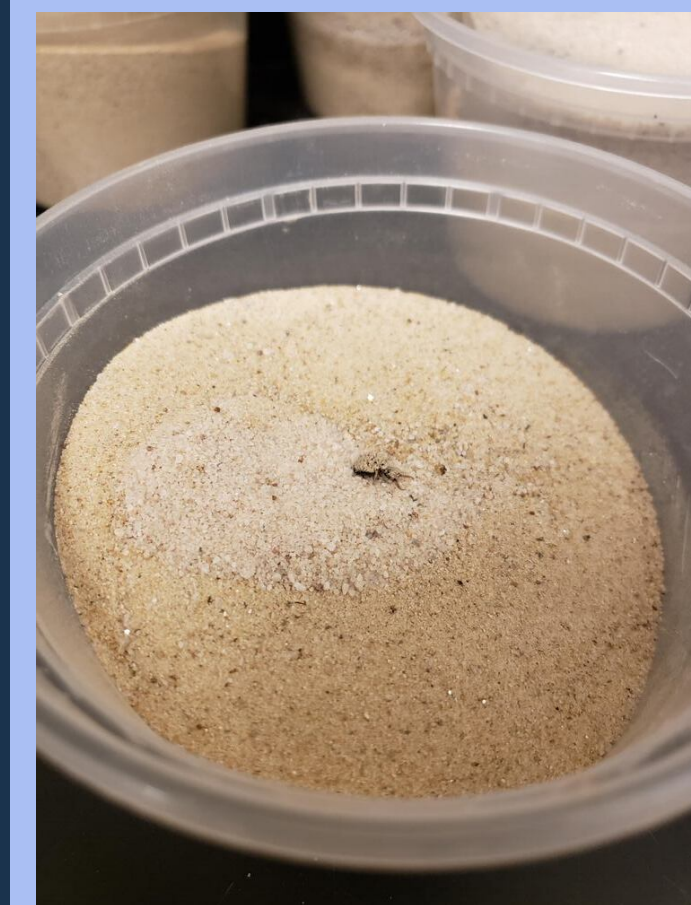


Fig 5: An antlion in the inter-trial holding containers with native sand



Fig 6: The full, original hosting container for antlions (32x33), with significant wandering

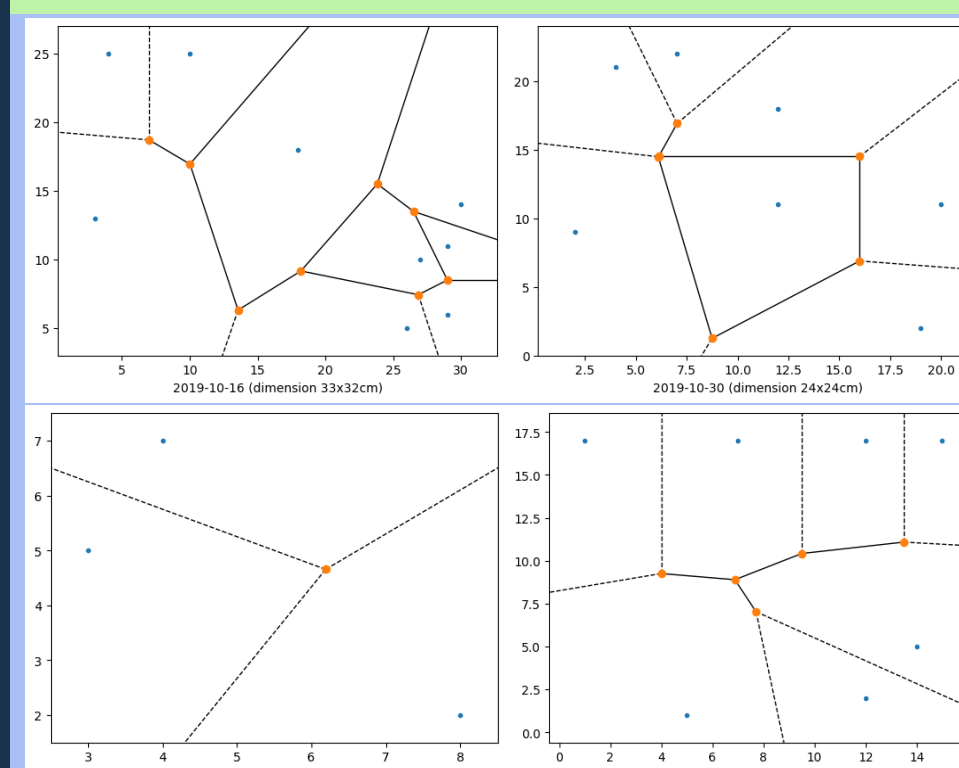


Fig 7: All of the antlion holding containers in the corner

Methods

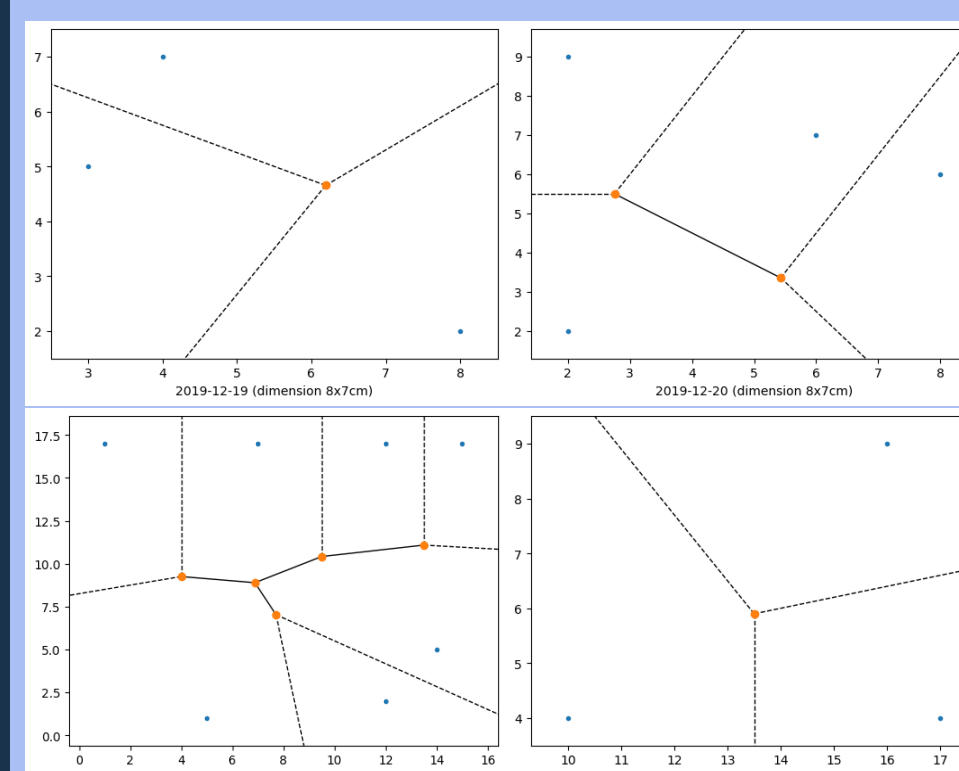
To start the procedure the materials needed to be obtained. Once materials were obtained the 160 ants were kept in one of the 6 inch plastic containers, and 200 grams of native sand was poured into each of the 40 remaining six inch containers. Next, each of the 40 antlions (*Myrmelcon immaculatus*) were placed in one of the plastic containers containing sand, with each antlion getting its own container. Following this each noticeable antlion pit was given two ants as food once every week, starting the Friday after the antlions were introduced to their temporary containers. Then, the remaining amount of sand was placed into the 32x32 container and spread out using a meter stick until the surface of the sand was level. Next, a meter stick was used to mark the sides of the 32x32 container with inch markers starting from the bottom right of the container on its lid. Much like a coordinate plane, marks were made one inch apart going vertically from the bottom of the lid of the container and subsequently labeled with their position away from the bottom of the box in inches, this acted as the y-axis. After this, marks were made one inch apart going horizontally from the right most section of the lid of the container and subsequently labeled with their position away from the right of the box in inches, this functioned as the x-axis. Next, the 2 inch cup was placed at the center of the container and buried under 3cm of sand. After this 4 antlions were introduced to the container every 24 hours until 30 antlions had been introduced, starting at 3:30 pm. This was done by using the sieve to obtain four random antlions from their temporary containers and place them on the center of the container, where the plastic cup was. Antlions were moved by using the sieve to remove the antlion from its six inch holding container. As new antlion pits appeared toothpicks were inserted next to them to signify their presence. Following the introduction of all 31 antlions a 24 settling period was allotted, after which the location of each antlion was measured using the grid system created earlier. Following this a program was used to find the nearest neighbor and a ruler was used to find the pit depth and width in cm. After data was taken the antlions were transferred back to their temporary containers by using a sieve to obtain the antlions from pits, where they were later placed in their temporary containers, dead antlions were kept in a freezer. Following this a barrier was inserted to reduce the available space to 24x23 inches using cardboard dividers and sealed using making tape, to prevent antlions from escaping the enclosure. After this another hour introductory period every 24 hours was repeated, will all remaining antlions, as some died in the previous trial. Once all antlions were introduced another 24 hour settling period was allocated and pit depth, width and location were found using the same methods as above, and the antlions were returned to their temporary containers. Following this the area of the box was reduced to 16x15 inches and all antlions were again introduced, 4 every 24 hours until all remaining antlions were placed in the pit. Then another 24 hour settlement period was allotted and all data was collected the same as as the previous three trials, and the antlions were returned to their temporary containers. Lastly, the area of the box was reduced to 8x7 inches and all antlions were again introduced, 4 every 24 hours until all remaining antlions were placed in the pit. Then another 24 hour settlement period was allotted and all data was collected the same as as the previous three trials, and the antlions were returned to their enclosures. To further understand the relevance of the study, the species of the antlions were examined through DNA barcoding. Using min PCR and a gel barcoding system the antlion DNA was extracted, and used a strand of mitochondrial DNA, cytochrome C in order to identify the antlions using a national protein database. The observed genus and species was *Myrmelcon immaculatus*.

Voronoi Diagrams



Individual Trial Voronoi Diagrams

The antlions were studied in several different (restricted) container sizes. These Voronoi diagrams which label the territories of each antlion (an antlion “possesses” a part of the map within its segmented portion if its pit (the blue dot) is closest to that point). By examination of the Voronoi diagrams in conjunction with measurement of the closest neighboring pit, it was determined that antlions reclude and cannibalize sufficiently to ensure roughly constant habitation density (proving, at least evolutionary, awareness of group strategies like allowing a few antlions to become adults very quickly).



Trial and subtrial Voronoi Diagrams

Two trial sizes were tested twice (earlier on left, later on right) because the antlions submerging themselves in the sand and became inaccessible. This shows that, when given appropriate time to develop new nursery conditions, antlions manage to successfully redistribute themselves. In the wild, this would correspond to a number becoming full adults and the remaining larvae rising to the surface. This indicates that they have advanced detective capability, likely without complex group-interactive cognition

Results

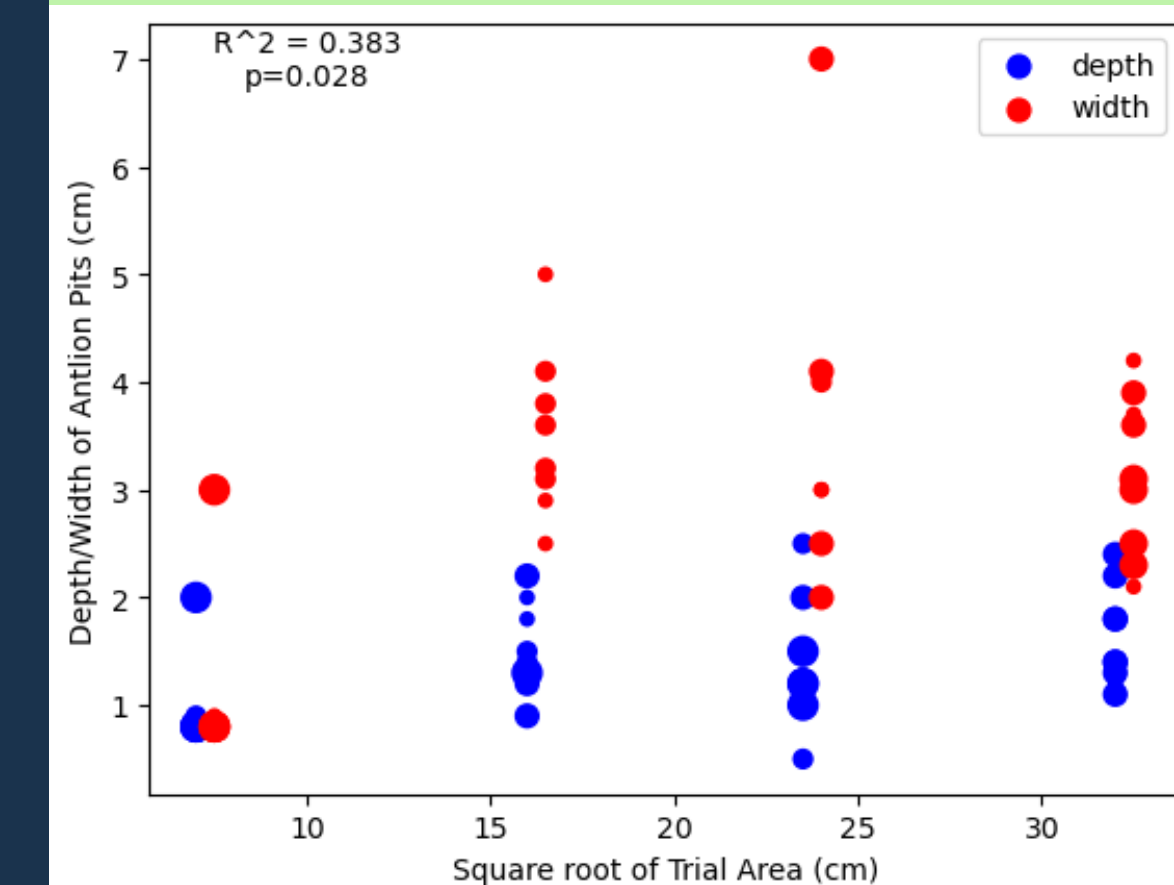


Fig 8: Antlions' pits' depths and widths correlate strongly with square root of trial area, meaning that antlions are aware of how to optimally obtain ants for the group. Bigger dots mean more pits of that size in that trial area

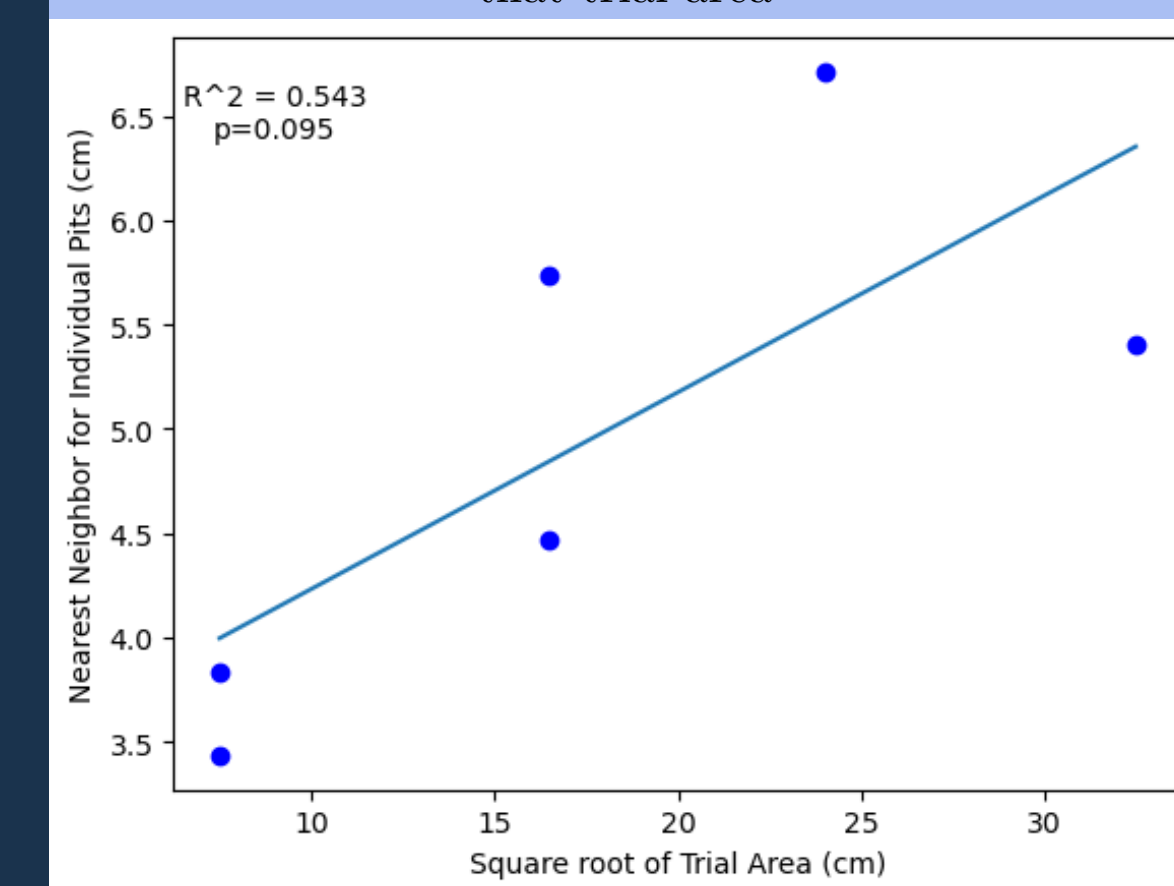


Fig 10: The geometric average of trial edge length correlates closely with nearest neighbor distance, demonstrating consistent spacing by antlions.

Table with 4 columns: Dimensions (in), Pit Depth (cm), Pit Width (cm), Nearest Neighbor (cm). Rows show data for various trial sizes (33x32, 24x24, 17x16, 17x16, 8x7, 8x7).

Fig 12: The Pit Depths, Widths, and “Territory,” Observed in Each Trial

Variables

Throughout the experiment the independent variable was the size of the container, which changed from trial to trial, but did not change due to any other variable. Furthermore, the dependent variable throughout the experiment was the settlement patterns and behaviors of the antlions (*myrmelcon immaculatus*), which was quantified through the nearest neighbor calculation, pit depth and width, and the number of cannibalized antlions. The control trial of the experiment was the 32x32 trial, as it shows the spatial patterns and behaviors of the antlions with the most available space, limiting the effect of competition on settlement patterns, which qualifies it to be a good control group.

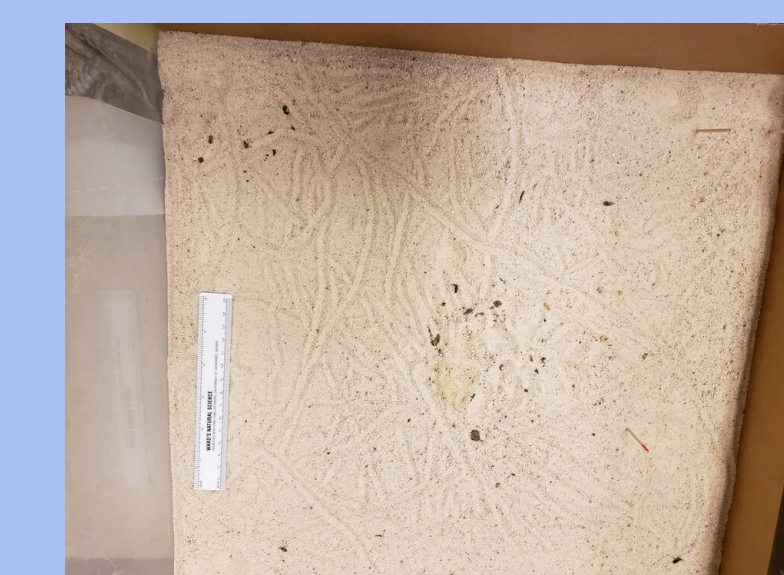


Fig 13: A photo of a relatively large trial showing the constancy of trails and establishment of one pit in a 16x17 container



Fig 14: 7 well-established pits in the 17x16 trial

Experiment Notes

Through the experiment several things were noted that could have improved the efficiency of the procedure and became a challenge, for example keeping track of the antlions became challenging as the experiment progressed, especially in the later trials when some of the antlions began to hide passively beneath the sand. Furthermore, removing the antlions from the enclosure after each trial became tedious, as it was difficult to find antlions that were under the sand or evaded capture. However, the setup and introductory periods both went well with each trial, as no major issues arose when setting the trials or when introducing the antlions. It was also noted that depth and width of the pits were smaller in trials with smaller enclosures and that antlions had roughly the same density across all sizes because they would become “dormant” if sufficient area was not readily available, both of which could be due to increased interaction between antlions within smaller enclosures. Measurement of the antlions' pits also became difficult, especially as the pits decreased in size (namely in the <1cm range), because parallax and “bumping” of the pits could introduce error. Lastly, cannibalism and death occurred at a relatively constant rate across all trials, indicating that cannibalism was more a function of time than a result of overcrowding.

Data Analysis

The patterns created by antlion groups are emergent: they don't exhibit top-down structure like a highly regular tiled or even consistent polymorphism across trials. However, the antlions (*Myrmelcon immaculatus*) did cluster somewhat (remaining close to each other despite available space, in some cases) but regardless maintained sufficient area to capture food, either of the cannibalistic or regular sort. These patterns likely developed, at least in the short terms these antlions were studied, by slow movement of the pits across the trial area, either by live migration or abandonment of old pits (which often occurred). The Voronoi diagrams are the primary source which exhibits these traits: scaled down to the window of the trial area which antlions populated, the area claimed by each individual antlion is somewhat consistent, explicable by a selfish algorithm: each antlion wants to optimize its area of ant capture (represented by “claimed” regions on the Voronoi diagrams), so the area was shared about equally by the group. Also, average distance to nearest neighbor decreased with lesser trial area: from 5–6cm on average in the 33x32cm trial down to 3–3.5cm in the 8x7cm trial, the graph in Figure 3 demonstrates a clear correlation, with a notable (but inconclusive) p-value of about 8%, between territorial area and total area. Additionally, compensatory behaviors were exhibited which further managed the population: cannibalism and reclusion both prevented surface overpopulation (because when two antlions were too close, one or the other usually occurred).

On the scale of individual pits, antlions optimize for energy. Unrelated to their partners' pits size, antlions typically size their pits to capture ants. Weekly feedings helped maintain the natural analogue to scarce ant feedings, so the antlions had to create their pits as determined by the density of the environment (simulated by a small area, which antlions readily detected despite their blindness by extensive trails created in the container). This caused them to create significantly smaller pits (so much so that at about .8cm deep and .8cm wide, measurement errors became excessively significant) in smaller containers (in terms of depth and width) because the antlions were aware that ants would, regardless, fall in rather than survive throughout the antlion colony. This is in contrast to the 33x32 where none of the antlions formed pits shallower than 1.1cm and one pit was 4.2cm wide. Furthermore, large pits may have become an unnecessary aggression or warning mechanism because, in order to preserve the larvae, the species would require sufficiently clear land that a group could populate the surface fully without unintentionally increasing cannibalism rates.

Throughout the study a clear increase in extreme behaviors was noted, which is shown by Table 1 (Appendix B, Figure 4), which shows that the initial 33x32 trial size had a 19.35% fatality rate among the 31 antlions involved in the trial, compared the last 8x7 trial size which had a 33.33% fatality rate. This resulted in a 13.9785% increase in deaths throughout the study, which falls within a p value of below 0.05, making the results statistically significant. The increase in deaths point towards increased cannibalism within the competing antlion population, as all deceased bodies were found with no head or appendages, but rather just a hard exoskeleton, leading to the conclusion that the antlions were cannibalized. The observed cannibalism of antlions supported the hypothesis that extreme behaviors would increase as trial size decreased, as antlions are known to resort to cannibalism in times of environmental and biological stress. Furthermore, the increased cannibalism was most likely a result of increased one interactions between antlions within a smaller trial groups, as the antlions in smaller trial groups have less space to settle in, increasing the chances that they will come into contact with another antlion. Increased cannibalism could also have been a result of increased competition at lower trial sizes, as in lower trial sizes food was not as spread out as much as it was in larger trial sizes, which could result in increased competition, leading to aggressive behavior such as cannibalism. Furthermore, extreme behavior such as reclusivity, measured in the total antlions without pits, barely changed in relation to the total antlions introduced in the trial, as a reclusivity percentage of 29.03% was noted in the 33x32 trial, and a reclusivity percentage of 25% was noted in the 8x7 trial (Appendix B, Figure 4), which is not statistically significant change. This led to the conclusion that as trial size decreases aggressive behavior such as cannibalism increases, however, pacifistic behaviors such as reclusiveness are not affected. However, because the total amount of pits observed in each trial decrease as trial size decreases, it is possible that antlions keep a ratio between the total amount of available territory and the number of active pits to avoid competition, as mentioned above in the territory calculation.

Both sets of behavior—extreme interactions like high levels of reclusivity or cannibalism and the spatial patterning of antlions under space constraints—are useful in models of the natural environments and behavior of antlion larvae. Reclusivity, for example, is an evolved behavior intended to allow as many larvae as possible to become adults as quickly as possible: rather than spread the wealth of ant food across a very large population, a partial proportion surface and would become adults within a matter of weeks. This is a protection mechanism against predators, and makes sense for the individual: reclusive behavior underground usually doesn't lead to death and below a certain threshold of energy intake, a pit on the surface doesn't make sense—especially considering the cannibalism risk. Cannibalism is partially an accidental behavior, but could certainly have some evolutionary implications: if the food supply runs low, antlions will move more and more antlions will be consumed by their peers to make up for the food supply. Furthermore, the increased surface density under more dense conditions, simulated by a small trial area, (rather than constant density with increasing reclusivity) means that antlions use population density as a proxy for food density because in nature, it would mean the area can support sufficient surface-dwellers. Antlions' behavior in the artificially constrained trial areas models closely their behavior in densely populated, constantly recycling nurseries, which explains the lack of highly regular structure.

Table with 5 columns: Trial Size, Date, Introduced, Deaths, Pits formed. Rows show data for various trial sizes and dates.

Fig 11: Number of Deaths and Pits Successfully Formed in Each Trial/Subtrial

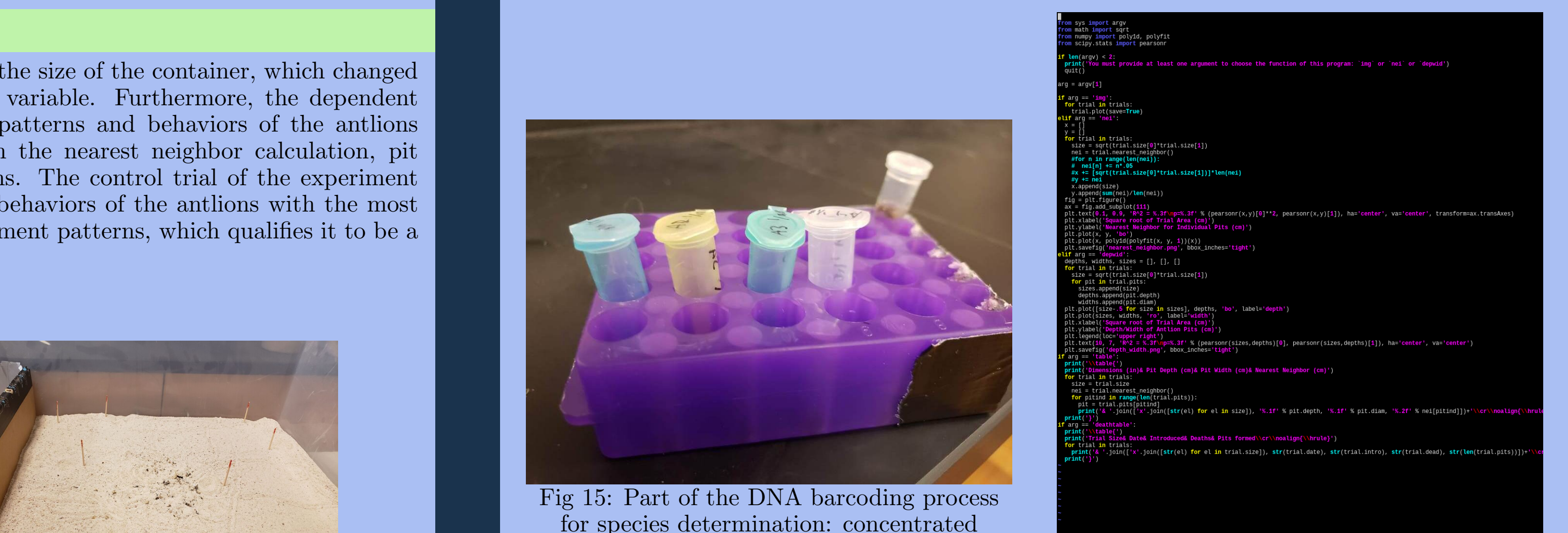


Fig 15: Part of the DNA barcoding process for species determination: concentrated mixture after chemicals, centrifuging, and crushing

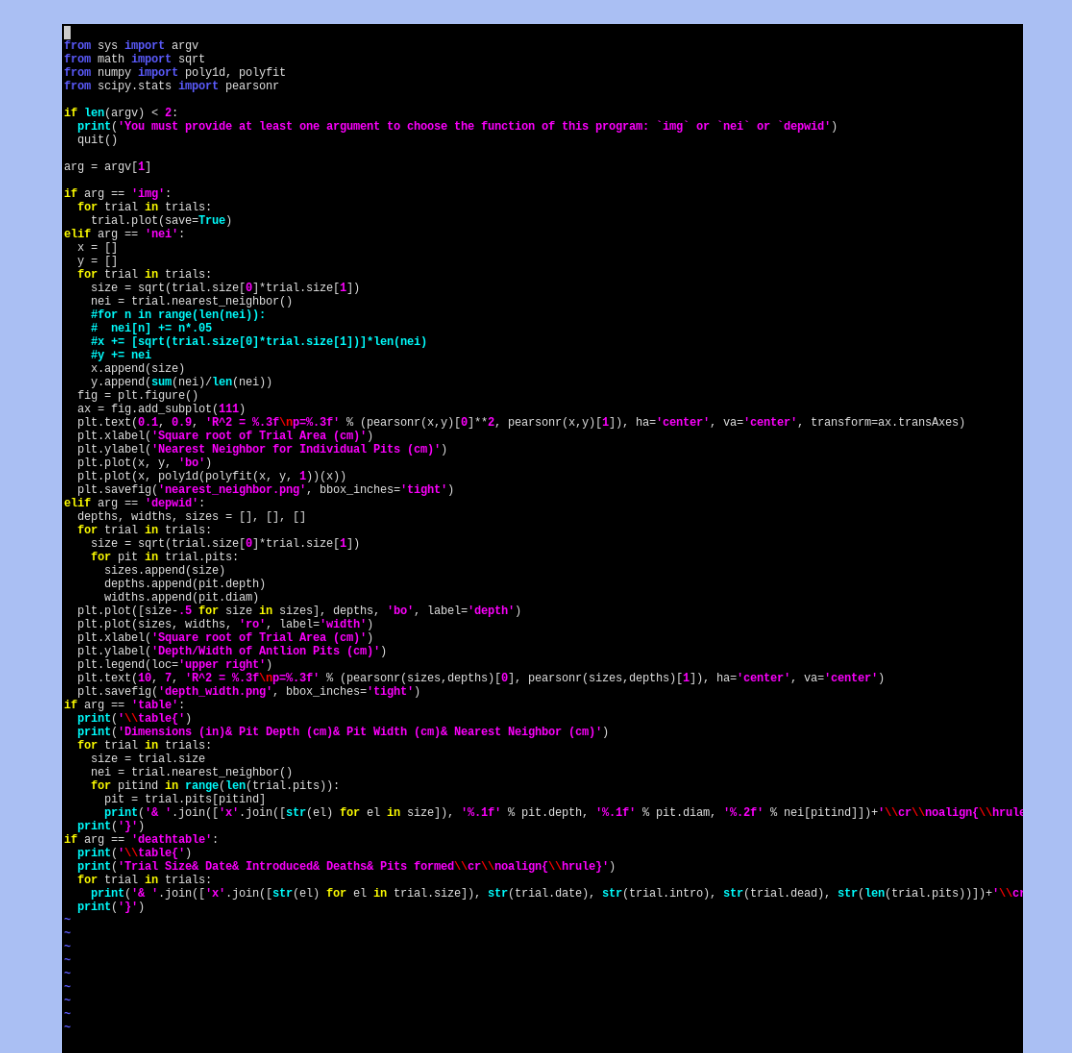


Fig 16: The code used to create Voronoi diagrams with SciPy and Matplotlib

Conclusion

Pit depth and width correlate strongly with trial area, as demonstrated by graph one, which relates the two. The pit positioning of antlions (as a group and as individuals) likely varies solely to maximize ant capture. Therefore, this phenomenon is observed because antlions' (*myrmelcon immaculatus*) pits don't need to be as big when the main constraint on ants falling into the pit is simply having a pit available for them to fall into. This is also observable by the trials' decreasing number of visible pits (versus total antlions introduced) with respect to size: they start to hide underground because rather than simply having smaller pits than stronger antlions, they have to rest underground, possibly to preserve group wellbeing. Graph 2 indicates a similar trend—antlions' territory as described by the nearest neighbor calculation is much lower in smaller containers. This is the natural consequence of less area being available but demonstrates that the effects of hiding don't completely level the density of antlion pits based on population per area. Additionally, deaths remain minimal even in highly crowded conditions like the 8x7, which means that deaths are probably accidental at worst and antlions work to preserve the group's chances of surviving. The earlier hypothesis was proven to be correct, as the correlation between a smaller trial size and more extreme behaviors (such as cannibalism and reclusiveness) is supported by the data, as an increase in cannibalism was seen in lower treatment groups, hinting towards more aggressive behavior at lower trial groups, thereby proving the hypothesis.