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Abstract: The leaf-cutting ant, *Atta cephalotes,* creates trails of foragers which carry leaf fragments to the nest. A division of labor is created based on ant body size (Stevens 1983). The smallest members of the caste system, the minima, "hitchhike" on the leaves of workers returning to the nest. My study was performed on a large colony in Monteverde, Costa Rica to research the cost of efficiency to the colony in relation to velocity with minima travelers. I hypothesized that load size affects velocity of the worker and predicted that an increased load size will negatively influence velocity. I collected *Atta* workers (n = 240) with leaf fragments and their minima and measured their velocity and ant, minima, and fragment mass. Though it was discovered that more minima travel on smaller leaves (χ^2 = 1990.13 p = < 0.001, df = 2), there was no significant relationship between increased load mass and velocity. The heavier load by the minima may be a trade off by foragers for the protection from parasitic flies that prey on workers.

Resumen: La hormiga zompopa, *Atta cephalotes*, crea senderos de forrajeo por los cuales cargan segmentos de hojas a sus nidos. Existe una división de trabajo basada en el tamaño de la hormiga (Stevens 1983). Los miembros más pequeños de este sistema de castas, las "mínimas", viajan en las hojas de las obreras que regresan a sus nidos. Realice este estudio con una colonia grande en Monteverde, Costa Rica, con el propósito de investigar el costo en eficiencia a la colonia de las mínimas. Mi hipótesis era que el tamaño de la carga afectaría la velocidad de las obreras y predije que un incremento en el tamaño de la carga influenciaría negativamente la velocidad. Yo recolecte obreras de *Atta* con sus fragmentos de hojas y sus mínimas y medí su velocidad y el peso de la hormiga, mínima y hoja. Aunque descubrí que más mínimas viajan en hojas pequeñas, no hubo una relación significativa entre peso y velocidad. Una carga más pesada por causa de la mínima pueda ser un intercambio por los forrajeadores por protección de las moscas parásitas que atacan obreras.

Introduction:

In neotropical forests, *Atta cephalotes*, a leaf-cutting ant, create highways of individuals carrying various leaf fragments back to their underground nest. The colony consists of approximately five million ants set in a caste system based on size differences starting with minima ants approximately 2 mm in length, media workers 10 mm, and soldiers 20 mm (Stevens 1983). Together they work to make these organized highways, constantly cutting, carrying, and depositing leaves in the nest. These pieces are cut and chewed, then placed into a large fungus garden (Holldobler and Wilson 1990). Larger colonies will forage 20-80 m away from the nest harvesting from trees, whereas smaller colonies have physically smaller workers and take from ferns and grasses (Wetterer 1994). However, questions arise as to how the hitchhiking minima riding on leaf fragments aid leaf-carrying workers. A 1995 experiment in Costa Rica, found that vibrations produced by foragers while cutting leaves was extremely effective in recruitment of minima. However, minima need to be in close proximity of the noise to have an effect on recruitment (Roces and Holldobler 1995). A study in Panama discovered a beneficial relationship between minima and *Atta* workers with its predator (family Phoridae). The investigation showed that the presence of hitchhikers significantly reduced the parasite's time spent on the leaves as well as the frequency of attack (Feener Jr. and Moss 1990). Hitchhikers were also observed to be preparing leaves prior to being deposited as they were traveling (Linksvayer et al. 2002).

The purpose of this study was to investigate if the minima have some effects on the velocity of leaf carrying ants in the colony. My hypothesis is that load size effects velocity of the worker. I predicted that a) with the presence of minima it will increase the load size and have a negative influence in worker's velocity and b) worker ants of larger masses will carry increased load sizes as well as more minima and c) larger leaves will have more minima.

Methods:

The study was performed in Bajo del Tigre, in Monteverde, Costa Rica. A large nest was used to collect observations. Two sticks were placed vertically into the ground 70 cm apart from one another along the *Atta* highway. A stopwatch was used to record the time it took for the ant to travel the complete distance. Time began the moment an ant crossed the starting line (first stick) and ended when it reached the second stick. The first 50 ants whose velocities were recorded were collected with their leaf fragment and minima and placed into numbered vials. Ants were collected for five days, however only 40 ants were collected on day 3 due to poor weather conditions. Vials were brought to the Monteverde Biological Station to measure ant mass, fragment mass, and minima mass on an electronic balance. Regressions were used to determine relationships for load sizes, minima mass, ant mass, and velocity. A chi square test was also performed to study frequency of minima as it varied between leaf size and velocity. Leaf categories were created based on mass: small (0.003-0.039 g), medium (0.040-0.079 g), and large (0.080-0.130 g). Velocity categories are: slow (.0034-.0099 m/s), medium (.0100-.0199 m/s), fast (.0200-.0273 m/s). Large minima were .003 g or higher.

Results:

Leaf fragments mass ranged from 0.003-0.126 grams. Ant mass ranged from 0.001-0.045 grams. Three regressions (Total load size Vs. velocity, Number of minima Vs. velocity, Leaf fragment size Vs. Velocity) were run and found to not be significant (Table 1). A positive relationship was seen between total load mass and ant size ($F = 162.92$, $p = < 0.001$, df = 1, figure 1a) and between minima mass and ant mass ($F = 11.5$, $p = 0.0008$, df = 1 figure 1b). The data also showed a positive relationship between both mass of minima and leaf fragment size ($F = 34.96$, $p = < 0.001$. df = 1, figure 2a) and number of minima versus leaf fragment size ($F = 12.58$, $p = 0.0005$ df=1, figure 2b). These two regressions (Fig. 2a and 2b) demonstrated relationships, however both had low R^2 values (0.128 and 0.050 respectively), which indicates a weak relationship. More minima travel on smaller leaves ($\chi^2 = 1990.13$ $p = < .001$, df = 2. figure3). A higher frequency of larger minima travel on leaves of slower workers ($\chi^2 = 153.69$ $p = < 0.0001$ df = 2, Figure 4).

Discussion:

The original hypothesis, that load size is related to velocity, was not supported by the data. An increased load size has no significant relationship with velocity. Colony efficiency in terms of velocity is maintained with hitchhikers traveling on leaves. As predicted, larger ants carried heavier load sizes. This is corroborated by a study in 1994, which found that larger ants on average cut denser leaves (Wetter 1994). Carrying a heavier load (which includes minima) may be more beneficial to the ant because of the protection from parasitic flies. Parasitic flies tend to prefer larger ants (Tonhasca Jr. and Braganca 2000) and therefore ants that are more susceptible may choose to carry minima. The higher frequency of larger minima traveling on slower individuals could also be explained by this benefit. The presence of minima on leaves decreases the frequency of harassment of predators (Feener Jr. and Moss 1990). It is also possible that the slower workers may be more prone to attack. The discovery by Freener and Moss (1990) leads me to believe this decreased harassment is the reason why slower travelers have more minima in their velocity category. We can see that as velocity categories increase, the amount of total minima being carried is decreasing (Fig. 3).

It is important to note that there is a higher total amount of minima traveling on smaller leaves. Since load mass and speed both have a positive relationship with ant size smaller ants most likely were taking smaller leaf fragments with minima (Rezania 2004). Since this study was performed in the morning, smaller ants may have been more common. A study found that susceptible foragers are protected against parasitism by a shift in the worker size distribution toward smaller, unsusceptible sizes during the day when parasitoids are active and larger ants at night when parasitoids are inactive (Feener Jr and Brown 1993). Larger ants may be more likely to be seen at night carrying minima on their larger leaf fragments. As stated above the slower moving ants may necessitate minima for defensive purposes. It's also possible this behavior developed as a defense mechanism against parasitic flies. Minima may appear larger to predators on smaller leaves as opposed to larger fragments and therefore reduce the amount of attack by flies. It would be interesting to see how minima body size plays a role in protecting the worker. Larger minima may cover more leaf area. Also a study on leaf size preferences of Phoridae flies attacking *Atta cephalotes* may shed light on this behavior. Future studies would benefit by using a different method of measuring the ants. Measuring body sizes, e.g. femur length, may lead to a more significant relationships because of more precise measurements of minima.

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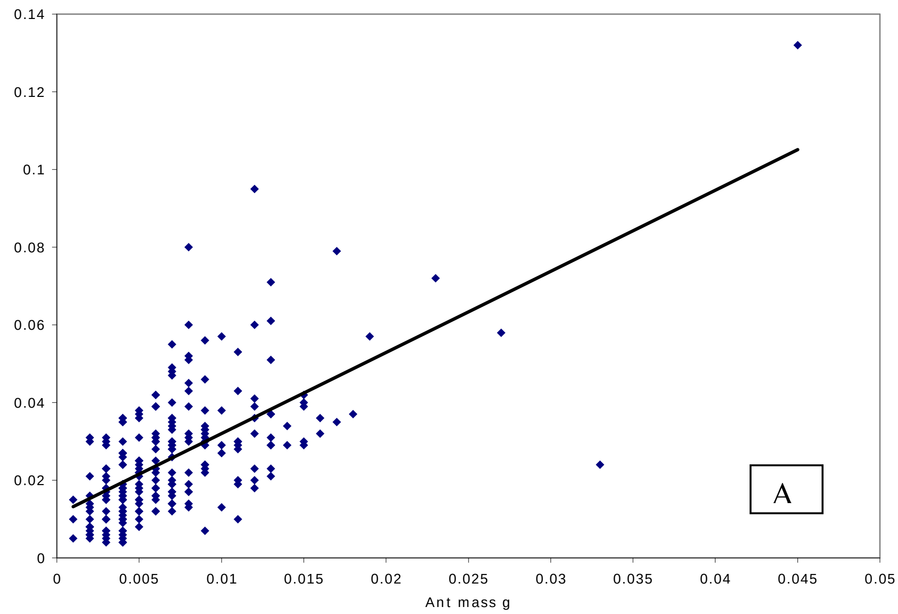
Table 1: Regressions preformed for *Atta* comparing velocity and an independent factor found to be insignificant. The data included 240 individual *Atta cephalotes* workers carrying minima on leaves and was collected over 5 days in Monteverde, Costa Rica.

Regression	F value	p value	df	R^2
Total load size Vs. Velocity	0.363	0.547	1	0.001
Number of minima Vs. Velocity	3.14	0.079	1	0.012
Leaf fragment size Vs. Velocity	0.366	0.545	1	0.001



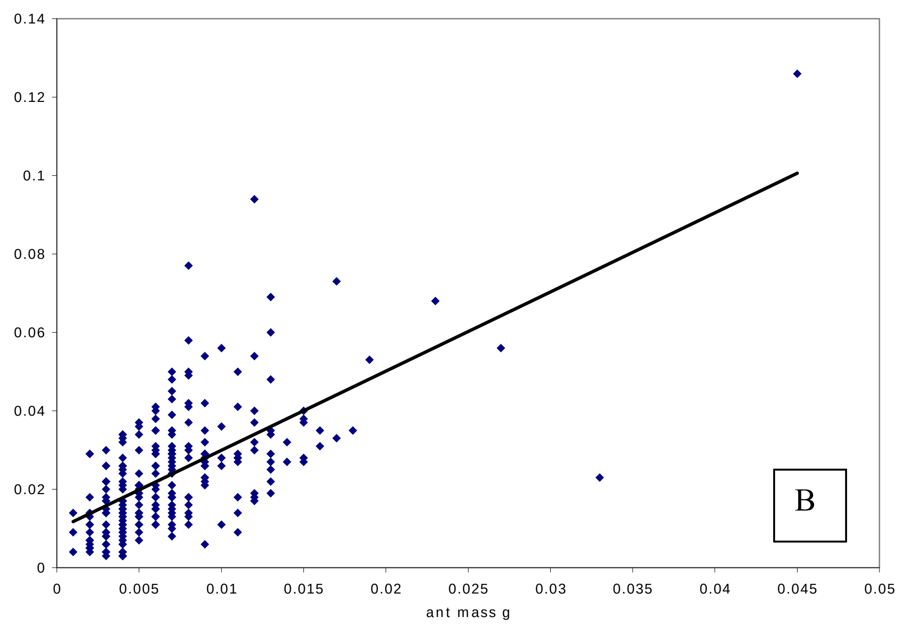
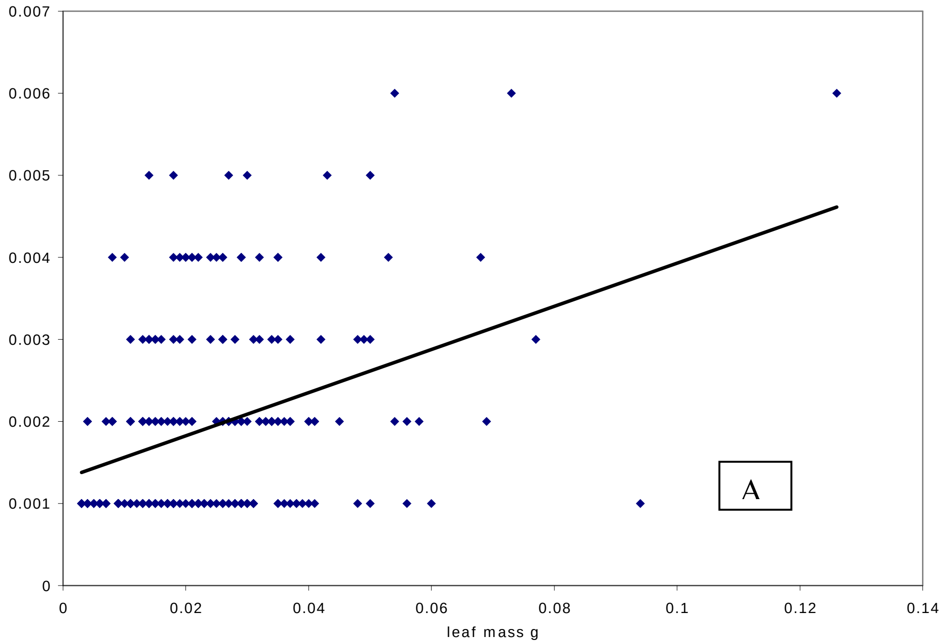


Figure 1: A) Ant mass versus total load mass. The minima mass and leaf fragment mass were added together and compared with work mass. The data included 240 *Atta* workers with minima that were weighed at the Monteverde Biological Station in Costa Rica. A positive regression was seen with linear equation: total load size y = 0.011 + 2.08X (R^2 = .406). B) Ant mass versus Mass of Minima (R^2 =.046, linear equation: mass minima y = 0.001 + 0.056 X). Minima mass only registered if the vial was not zeroed on the scale; consequently only whole values were seen.



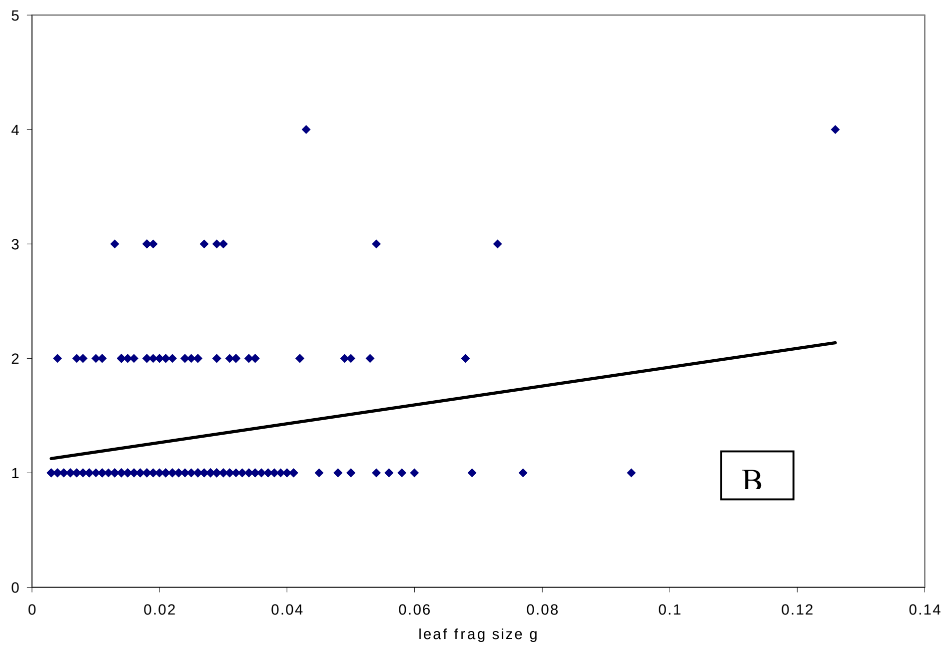


Figure 2: A) Minima mass vs. Leaf mass. A positive relationship was shown in *Atta* workers collected in Costa Rica. Linear Relationship: mass minima y = 0.001 + 0.026X. B) Number of Minima vs. Leaf mass shows a positive relationship. Linear equation: # minima y = 1.10 + 8.22X

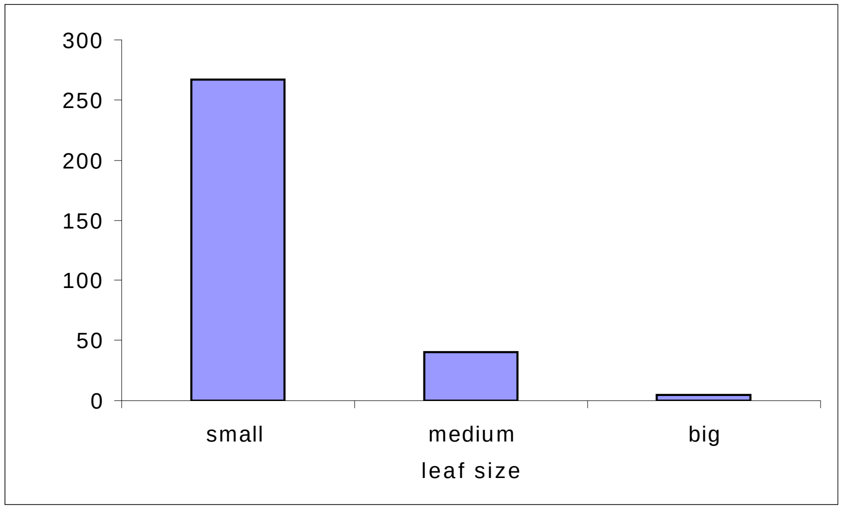


Figure 3: Total number of minima in leaf size category. Leaves carried by *Atta* were subdivided by size: small (0.003-0.039 g), medium (0.040-0.079 g), and large (0.080-0.130 g). More minima were found on smaller leaves.

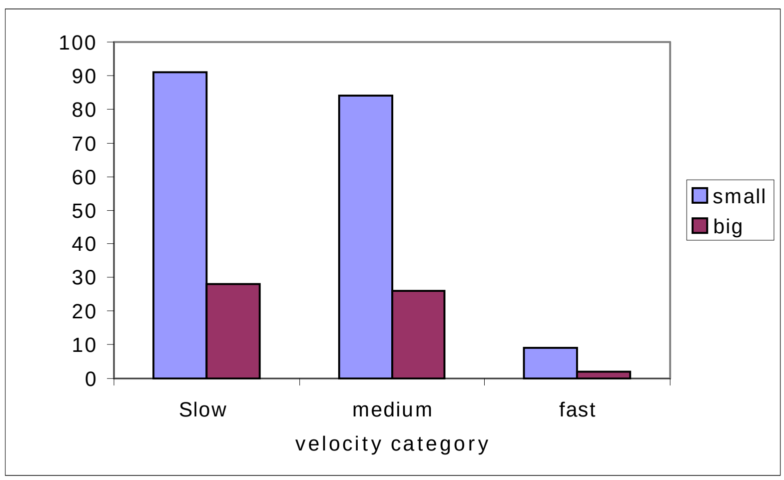


Figure 4: Total number of minima separated by mass and velocity. Velocity categories are: slow (.0034-.0099 m/s), medium (.0100-.0199 m/s), fast (.0200-.0273 m/s). A large minima was .003 g or higher. There is a higher frequency of larger minima mass on individuals in the slower category.