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Nest Emigration Behavior of the Asian Needle Ant, *Brachyponera chinensis* Emery (Hymenoptera: Formicidae)

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Abstract

Ant colonies change nest location in response to physical disturbance, climate fluctuation, and resource availability. During the emigration process, worker recruitment is vital to ensuring that individual colony members are moved to the new nest site. Recruitment methods used during emigration differ between ant species. In a laboratory study, we investigated the recruitment behaviors of the invasive Asian needle ant, *Brachyponera* (=*Pachycondyla*) *chinensis* (Emery), during nest emigration. Subsets of *B. chinensis* worker ants were subjected to physical nest disturbance, and the recruitment methods and associated behaviors were recorded. Before recruitment to the new nest location began, *B. chinensis* ants organized into three distinctive groups: queen-tending, brood-tending, and scouting. Once the new nest site was identified, scout ants began physically transporting nestmates into the new harborage. Transport rates increased with time in the first 30 minutes and did not change during the 30 to 55 minute interval when brood was transported. However, adult transport rate increased again after brood transport was completed and decreased after 90 minutes. These studies are the first to identify the recruitment methods, division of labor, and social organization behavior of *B. chinensis* during nest emigration.

Introduction

The process of nest emigration is essential to the propagation and establishment of ant colonies. Many ant colonies are labile with members changing nest location in response to drought, flooding, predation, competition, budding, and nest disturbance (Fowler, 1981, Tay & Lee, 2015). Although emigration is a familiar process, recruitment methods during emigration differ between and within ant species (Hölldobler & Wilson, 1990; Planque et al., 2010). Recruitment methods include pheromone trail following, tandem running, and physical adult transport (Maschwitz et al., 1986, Beckers et al., 1989). A single species may employ a variety of recruitment methods during an emigration event. For example, *Bothroponera tesseronoda* (Emery) uses tandem running and trail following to complete emigration (Jessen & Maschwitz, 1986), whereas tandem running is preceded by adult transport in *Neoponera obscuricornis* (Emery) (Traniello & Hölldobler, 1984) and *Leptothorax albipennis* (Curtis) (Pratt et al., 2002).

Adult transport by ants was initially characterized solely as a nest emigration recruitment method (Haskins and Haskins 1950). However, Guénard and Silverman (2011) re-described the physical transport methods of the invasive Asian needle ant, *Brachyponera chinensis* (Emery), during foraging expeditions (Takimoto, 1988). The foraging recruitment method, tandem carrying, is a newly described context-dependent recruitment behavior, occurring three to ten times more often when a food item is too large to be moved by a single worker. In addition to being a new foraging strategy, tandem carrying was further distinguished from other forms of adult transport because the carrying posture differed from previously described

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transport postures (Guénard & Silverman, 2011). In other ant species, worker ants are grasped and/or transported by the mandibles, the neck, or on their side (Möglich & Hölldobler, 1974), whereas ants being transported during tandem carrying are grasped between their first and second pairs of legs on the ventral mesothorax. Guénard and Silverman (2011) described this region as the mesometasternum but this designation is incorrect, as the sternites on ants are internal invaginations and not external features.

Research on *B. chinensis* has increased due to its potential as a public health threat (Cho et al., 2002; Nelder et al., 2006; Lee et al., 2009), negative impact on native and introduced ant species populations (Guénard & Dunn, 2010; Bednar et al., 2013; Spicer-Rice & Silverman, 2013), spread in the southeastern U.S., and potential spread into areas outside its current range (Bertelsmeier et al., 2013). *B. chinensis* typically nests in downed timber or under objects in contact with the soil, usually in areas where termites are abundant, contributing to their success (Bednar & Silverman, 2011). Identifying and determining the potential for geographic spread and nesting behavior are central to understanding the invasive ecology of *B. chinensis*.

During field and laboratory observations, *B chinensis* workers engaged in adult transport. The observed transport took place in the absence of immovable food items. The ants were physically transporting nestmates to various locations in space but we did not identify any subsequent tasks. Because adult transport occurred outside of foraging recruitment and is commonly associated with nest emigration, we hypothesize that *B. chinensis* employ adult transport to complete nest emigration using the posture assumed during tandem carrying reported by Guénard and Silverman (2011). In the laboratory study reported here, field-collected colony fragments were subjected to identical nest emigration trials elicited by physical disturbance to determine the recruitment methods of *B. chinensis* during emigration. Also, in a separate study, ants were marked with paint and subsequently subjected to nest emigration trials to determine the extent of task allocation during nest emigration in *B. chinenesis*.

Materials and Methods

Twenty queen-right *B. chinensis* nests were collected from different locations within the Clemson Experimental Forest, a mixed hardwood-pine forest in Pickens County, SC ($34^0$43'55.018" N,$82^0$51'6.654" W) between August-October 2012 and April-June 2013. Each nest used in the study contained at least one queen, brood, and 200 worker ants. Laboratory trails were conducted between September-November 2012 and April-June 2013. Collected nests were subjected to experimental trials within one week of collection. Ants nests were housed 20 gallon uncovered plastic tubs (40.89 cm x 39.06 cm) and provided with a glass test-tube (250 mm x 25 mm) wrapped in red transparent cellophane with a piece of moistened cellulose sponge inside as a water source (Figure 1). Test-tube harborages were used to mimic *B. chinensis* galleries in fallen timber. Colonies were fed *Reticulitermes* sp. workers, and *Tenebrio molitor* (Linnaeus) larvae *ad libitum,* and maintained at 21°C at a 12:12 L/D cycle with 70-80% RH.

All studies were conducted in arenas consisting of a plastic container (60 cm x 42 cm x 16 cm) divided into equal halves by a 37-cm acrylic glass insert (Figure 1). Before testing began, an uninhabited glass test-tube harborage was placed in one half of the arena, and the other half remained empty. Because the acrylic glass insert was not completely flush with the bottom of the arena, 37-cm strips of Play-Doh® (Hasbro Corporation, Pawtucket, RI) were used to seal openings. Worker ants inspected Play-Doh® strips but did not attempt to feed on or remove the inserts.

Colony emigration studies were conducted concurrently in separate treatment (n = 10) and control (n = 10) arenas. Overall, ten colonies were used per treatment. On the day of experimentation, a colony subset consisting of 200 workers, one queen, and 20 brood items (eggs, larvae, or pupae) were manually removed from two separate colonies and transferred to two different glass test-tubes (250 mm x 25 mm) using featherweight forceps and/or a small paintbrush. Each test-tube, wrapped in red transparent cellophane, contained a piece of moistened cellulose sponge as a water source (Figure 1). After removal, the test subjects were allowed to acclimate to the new environment for two hours. Treatments consisted of a physical nest disturbance, defined as manually removing all nest members and associated materials from a test tube harborage. Specifically, during disturbance, the sponge insert was removed and the test tube was lightly shaken to dislodge any ants remaining in the test tube. Any ants latching onto the sponge insert were removed using a paintbrush. Test-tube harborages were not physically disturbed in control treatments. In each round of experimental trials two colonies were selected. Selected colonies were randomly designated as "treatment" or "control" and were used once during the study. In both treatments, the Play-Doh® barrier and plexiglass inserts were removed from the arenas after a one-hour acclimation period, permitting unrestricted ant movement.

Data collection began after the first successful carrying event was observed. Successful transport consisted of the carried individual being released inside the new harborage. All carrying events were visually observed, time of carry was recorded, as well as the total number of successful carries. Data collection ceased after 90 minutes. Preliminary data indicate, after this time, the interval between carrying events was greater than five minutes. A one-way Wilcoxon test was conducted to determine differences between total number of successful transports occurring in treatment and control arenas during nest emigration trials (JMP® Pro 10, SAS Institute, Inc. 2012. Cary, NC). A P-value of < 0.05 indicated statistical significance. The difference in number of ants being carried in 15-minute intervals was compared using a Repeated Measures MANOVA in SAS 9.3 (SAS Institute, Inc. 2012. Cary, NC). A P-value of < 0.05 indicated statistical significance. All raw data provided as Supplementary Material.

Fig 1. *Brachyponera chinensis* nest emigration arena (60.9 cm x 42.6 cm x 16.7 cm) with test tube (250 mm x 25 mm) harborages, plexiglass insert, and Play-Doh® lining. Test tubes are wrapped with red cellophane paper with a moistened 8-cm sponge inserted. During experimental trials, the plexiglass insert, Play-Doh®, and one harborage were removed allowing the ants to freely move in the arena.

Task Allocation

To determine if *B. chinensis* workers performed repeated adult transport episodes during emigration, worker ants were marked with paint and subjected to physical disturbance. The ants used in the current study were obtained from four of the nests used in the previous study. As part of the study, two hundred worker ants were removed from a colony along with one queen and brood. Queen ants and brood items were not marked with paint during trials. Before marking, five ants were selected, placed into a 1.5 mL plastic medicine cup, and transferred to a freezer (-18 ^{0}C) for 2 minutes. After removal from the freezer, the ants were transferred from the medicine cup to onto a chilled metal panel. To mark an ant, a single ant was placed onto a foam platform with a single strand of hair taped down as a loop. The hair loop served as a restraint for the ants. Worker ants were marked on the head, abdomen, or thorax with Testors® modeling paint (Testors,Vernon Hills, IL) to distinguish workers. After marking, each ant was placed into a plastic container (60 cm x 42 cm x 16 cm). The queen ant and brood items were transferred to the arena after the worker ants were distributed. A glass test 250 mm x 25 mm) wrapped in red transparent cellophane with a piece of moistened cellulose sponge inside as a water source was added to the arena to elicit emigration. Observational data was recorded but statistical analyses were not performed. Pictures of worker and queen assemblages during nest emigration trails were taken with a Sony Cybershot® camera (Sony Corporation of America, New York, NY). All images provided as Supplementary Materials.

Results

Brachyponera chinensis workers used adult transport as a recruitment method during nest emigration. In total, we observed 396 successful transport events in treatment arenas and 42 in control arenas. The mean number of successful transports occurring in treatment arenas (39.6 ± 6.94 SD) was significantly more than the number of successful transports observed (4.2 ± 2.2 SD) in control arenas (see Supplementary Materials). Treatment had a significant effect on the number of successful transports occurring during the study (Wilcoxon Test, x^2 = 14.35, p = 0.0002). On average, 19% of ants were physically transported inside the new harborages. The remaining 81% of ants walked into the new harborage without worker assistance.

We observed workers in treatment arenas organizing into task-associated groups before acrylic glassinserts were removed. Groups consisted of brood retrievers, members of the queen's tending group, and scouts (see Supplementary Materials). Queen-tending ants surrounded the queen, remaining with the group until the queen walked into the new harborage. Scouting groups consisted of transporting and non-transporting worker ants. Non-transporting scouts moved around the arena but not in a particular pattern. After the insert was removed, ants either remained in groups or began walking into or under the new test tube harborage. Adult transport began after several scouts explored the new test tube harborage 12-15 minutes after the trial began (Figure 2).

The number of successful transports occurring every fifteen minutes in treatment arenas was compared. Results indicate that the number of transports did change with time (F= 62.58,p = 0.0002). Once initiated, transport continued at a steady rate for 30 min. (Figure 2). Transport rates remained constant from 35 to 50 minutes. During this period, retrieval and placement of brood from the open arena into the new harborage became the focus of non-transporting ants. Queen ants were also moved during the 35-55 minute period. After 55 minutes, the number of successful transports increased again for 15 minutes on average.

When transporting scouts encounter other ants, the pair interacts by drumming their antennae together. In each successful case, the ant being transported lowers its head, allowing the transporting ant to grasp it by the mandibles. From this position, as defined by Guénard and Silverman (2011), the carried ant assumes a pharate pupal posture and eventually is grasped on its venter. The pair then walked toward the harborage; however, the path to the new nest site may not be direct. Once the pair reaches the new nest, the carrier ant releases its nest mate within the harborage. The carrier may remain inside the nest or return to the arena after releasing its nestmate.

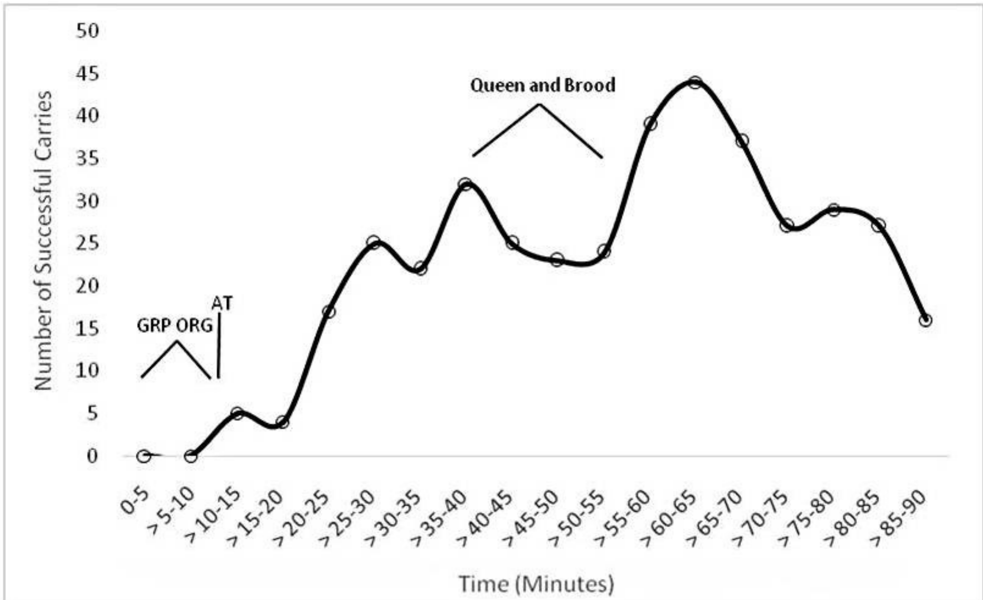

Fig 2. Pooled total number of successful carries by B. chinensis workers occurring at 5-minute intervals during treatment nest emigration trials (n = 10 colonies). Worker ants organized into groups (GRP ORG) FROM 0-13 min. Adult transport (AT) began at the 12 min and continued for 90 min. Queens and brood were transported from 35-55 min. The number of successful transports performed by B. chinensis workers decreased during queen and brood movement. Transport activities increased after the queen and brood were moved to the new harborage.

The marking experiments were not successful but one ant was observed performing two consecutive transports. The marked ant picked up a nestmate dropped her off inside of the harborage and immediately entered the arena to retrieve another nestmate. Consecutive transporting was not observed in any of the other trials.

Discussion

Social carrying in *B. chinensis* was initially characterized as a context-dependent behavior performed only to recruit nestmates to food items too large to be carried by individual ants, a process known as tandem carrying (Guénard & Silverman, 2011). The data presented in the current study indicate that *B. chinensis* workers also employ adult transport during nest emigration.

In some ant species, adult transport during emigration is sometimes preceded by tandem running (Möglich, 1978; Traniello & Hölldobler, 1984; Pratt, 2005). *Brachyponera chinensis*, however*,* do not employ multiple methods during emigration. On average in this study, 19% of workers were physically transported into the new harborages during trials and the remaining 81% traveled alone to the nest site. Consequently, the question of how non-transported ants locate new nest sites remains unanswered. Non-transported ants were observed walking directly into the harborage without exhibiting tandem-running or trail-laying behavior. However, for a worker ant to locate the new nest site, directional cues must be present. Guénard and Silverman (2011) attempted to determine if *B. Chinensis* use trail pheromones during tandem carries, but their experimental results were inconclusive. However, the use of trail pheromones should not be discounted. To exclude pheromones as a contributing factor, gaster positions during emigration must be analyzed and extractions of glands commonly associated with pheromone production, such as the Dufour's gland or pygidial gland should be made (Holldobler et al., 1982). In addition to chemical signaling, tactile and visual signaling should also be evaluated as directional cues used by *B. chinensis* during emigration.

Although adult transport is an effective recruitment strategy for *B. chinensis*, each carrying attempt is not successful. The "transporting" ant always initiated the process in this experiment, but the "transported" ant may resist. Resisting ants pull away from the transporter or place their thorax/abdomen on the floor of the arena, preventing the other ant from gaining the leverage needed for carrying. This observation lies in accordance with Langridge et al. (2008) who documented comparable behaviors in *Temnothorax albipennis* (Curtis) during colony emigration.An unsuccessful transport could be the result of a "transporter" ant encountering an individual that previously experienced visiting the new nest, another "transporter", or encountering an ant responsible for protecting brood or the queen.

Before initiating transport, *B. chinensis* worker ants organized into groups. Groups consisted of scouts, brood tenders, and the queens' retinue. Scouting ants spent time exploring the foraging arena and were the first to locate the new nest. It appeared that worker ants were protecting the queen during emigration. Queen protective behavior during emigration was also observed in *Oecophylla longinoda* Latrielle, the weaver ant (Holldobler & Wilson, 1983). *Oecophylla longinoda* queen sexude exocrine gland produced pheromones that attract workers to the queen during emigrations, allow workers to produce trophic eggs, but prevent workers from producing viable developing eggs. The loss of worker egg production ensures that queens are the sole producer of life within a colony making her a vital asset to the longevity of the colony. Worker ants of *B. chinensis* (Ito and Ohkawara, 1994) and its sister species *B. nakasujii* do not possess ovarioles (Gotoh & Ito, 2008). As a result, *B. chinensis* colonies solely depend on the queen for egg production. The presence of queen retinue in *B. chinensis* and absence of ovarioles in *B. chinensis* worker ants may be linked to queen produced pheromones. Brood items and the queen were transported during the middle (35-50 min.) of the study. Queen movement during this period is consistent with Pezon et al. (2005) in which *N. obscuricornis* queens were transported mid-way through emigration presumably to optimize their protection.

The number of potential transporters was lower than the number of potential transportees suggesting that a small proportion of the total workforce is allocated towards adult transport. Previous studies show similar results (Langridge et al., 2008, Sendova-Franks & Franks, 1995) but studies attempting to identify if carrying behavior was relegated to a specific group of ants during emigration have been inconclusive (Sendova-Franks & Franks, 1995). However, physical marking caused workers to devote more time to grooming than to colony tasks. Yet, in one marking trial, we documented one marked ant carrying thirteen nestmates into the new harborage. In view of repeat transports, we anticipate that *B. chinensis* workers are capable of performing multiple carries, but additional marking studies are needed to determine the worker antcarrying frequency.

Colony duties may also be associated with a worker ant's age, a phenomenon known as temporal polyethism (Robinson et al. 1994, Sendova-Franks and Franks 1993). In some studies, younger ants tend to work within the nest whereas older ants usually take on tasks outside the nest, such as colony defense, foraging, and recruitment. During trials, we observed workers transporting dusky-yellow colored, callow workers into the nest, but callow workers never behaved as transporters. Abraham and Pasteels (1980) reported similar behavior in *Myrmica rubra* (L.). Recognition of this phenomenon raises the possibility that temporal polyethism also may play a role in task allocation during adult transport in *B. chinensis*.

As *B. chinensis* continues to increase its geographic range (Guénard & Dunn, 2010), thorough documentation of colony movements will be more important. The dispersal abilities of invasive ant species are affected by dispersal type. After establishment, invasive ants may naturally increase their range by mating flights (Markin et al., 1971) or increase their foraging range through an emigration process known as budding (Holway et al., 2002). During budding a portion of a colony leaves the original nest to found a new nest a few meters away. *Brachyponera* use adult transport during foraging (Guénard & Silverman& 2011) and during nest emigrations (current study) so it is possible to suggest that ants also use adult transport to increase their range.

Our studies serve as the first to provide insight into the nest emigration recruitment behaviors of *B. chinensis* workers. In this laboratory study, *B. chinensis* employed adult transport during emigration to move colony members to new nesting locations, but only a subset of the entire colony was relocated in this manner. These results suggest that *B. chinensis* may disperse through budding. However, Zungoli and Benson (2008) collected winged males and females in a light trapping study, suggesting that mating flights may also occur; although, males alates were trapped more frequently than females (19:1). Future studies of *B. chinensis* emigration should attempt to address colony propagation and task allocation during emigrations. Studies of this nature will help us understand dispersal factors contributing to the invasive success of *B. chinensis* in the United States.

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Supplementary Material

http://periodicos.uefs.br/index.php/sociobiology/rt/suppFiles/1586/0

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